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TECHNICAL REPORT ARBRL-TR-2030

RAYMAN: A FORTRAN COMPUTER CODE FOR TRACING RAYS THROUGH A DETAILED HUMAN PHANTOM

William B. Beverly

November 1977

Approved for public release; distribution unlimited.

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
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A FORTRAN computer program RAYMAN has been written that simulates an average human adult male in a hostile ballistic environment. Projectiles are picked from a user-chosen ballistic threat and those striking the phantom human are tracked to their exit from his body. Ballistic vulnerability factors, associated with the physiological detail of the phantom, are retrieved at regular intervals along the shotlines of the impacting projectiles. The retrieved vulnerability factors are averaged over many shotlines to yield a histogramic

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representation of the average vulnerability factor versus tissue penetration. Results are printed in tabular form along with identifying captions.

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I. INTRODUCTION

A description of a standard man (the Computer Man)[1] has been built by the Target Assessment Branch (TAB), Vulnerability/Lethality Division (VLD), Ballistic Research Laboratory, using the properly-chosen, horizontal, anatomical cross sections (slices) collected by Eycleshymer and Schoemaker[2] (see Figure 1). These slices have been uniformly gridded so that the physical detail of the Computer Man can be referenced by a Cartesian lattice. Current descriptions assume that all tissue in a cell is the principal tissue in that cell. The two currently-used lattices have a 0.5 cm and 1.0 cm horizontal grid respectively and both descriptions use 2.6 cm thick lower-body slices and 1.2 cm thick upper-body slices.

A phantom of the man, when used for incapacitation studies, is assumed to be standing in a box that barely encloses him. The box is placed in the first octant of a Cartesian coordinate system so that the sides of the box are parallel to the coordinate-axis planes. A bottom corner of the box is located at the coordinate-system origin so that the phantom faces the positive-y direction.

A three-dimensional matrix is constructed whose elements reference the Computer Man cells. The matrix is currently filled with the mortality rankings gathered by Cooper[3] but it can be used to store other, user-chosen quantitative descriptions. The indices of the cell enclosing a point in the phantom man may be calculated and used to retrieve the corresponding matrix element.

The FORTRAN Computer Code RAYMAN can generate rays whose origins and directions are picked from user-selected distribution functions and project them into a phantom of the Computer Man. Promenades are conducted along the rays as they penetrate tissue and a point is picked uniformly along each step. The mortality ranking, M, corresponding to the cell enclosing the point, is retrieved and added to those retrieved for the same tissue penetration, R, along earlier rays. A histogramic representation of the mean mortality ranking, $\overline{M}$, versus R is calculated at the end of a statistically meaningful sampling of rays and the results are printed in tabular form. This output may be used to assess personnel vulnerability to the ballistic threat as discussed by Kokinakis and Bruchey.[4]

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1. *Charles A. Stanley, Michael Brown, "The Computer Man," to be published as a BRL Report.*

2. *Albert C. Eycleshymer, Daniel M. Schoemaker, "A Cross-Section Anatomy," D. Appleton-Century Company, Inc., New York, London 1938.*

3. *Walter R. Cooper, William Kokinakis, "Vulnerability Rankings of Human Tissue," to be published as a BRL Report.*

4. *William Kokinakis, William J. Bruchey, "An Engineering Approach to the Assessment of Personnel Vulnerability," American Defense Preparedness Association, October 1975.*

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SLICE NO.	ANATOMICAL SECTION	DISC RECORD NO.
(1 - 6)	FEET	1
(7 - 33)	LEGS	2,- 6
(34-39)	ARMS, LEGS	6,- 7
(40-59)	ARMS, TORSO	7, - 10
(60-64)	TORSO	10, - 11
(65-82)	HEAD	11,- 14
(83-84)	DUMMY SLICES	14

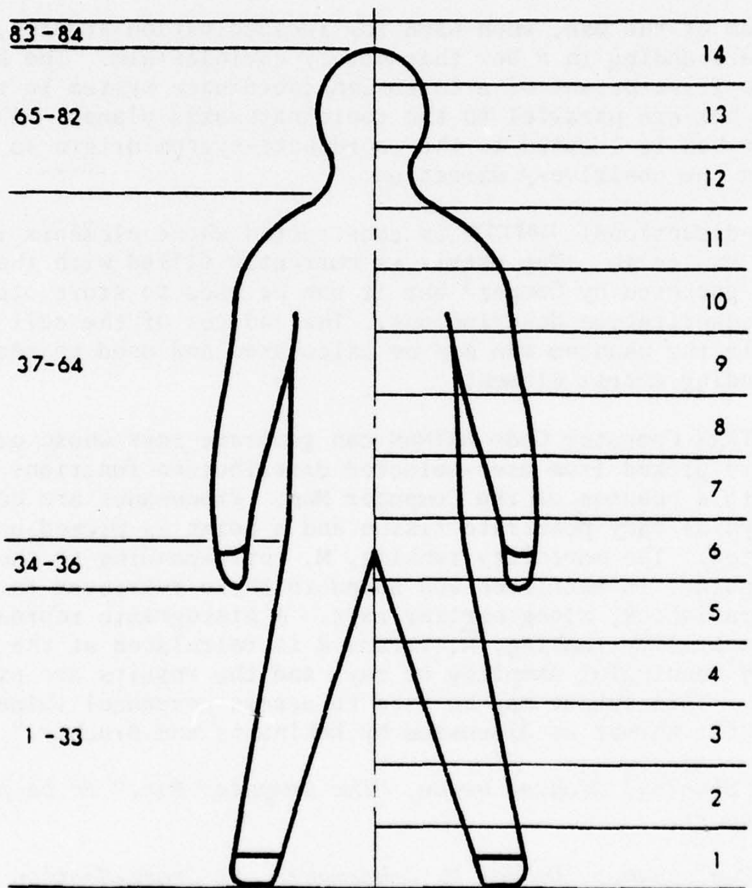


Figure 1. The Computer Man Layout

II. CODE CAPABILITY

Simulated projectiles (rays) can be started from origins whose locations are picked from a user-selected choice of nine different distributions. The distributions are:

1. User-supplied coordinates. The present dimensions of the storage arrays permit the user to submit a maximum of 100 points.

2. Points generated uniformly on the overhead hemisphere. The user will choose the radius for all hemispherical origins.

3. Points generated uniformly on the underfoot hemisphere.

4. Points generated uniformly on the $X > 0$ hemisphere.

5. Points generated uniformly on the $X < 0$ hemisphere.

6. Points generated uniformly on the $Y > 0$ hemisphere.

7. Points generated uniformly on the $Y < 0$ hemisphere.

8. Points generated uniformly on a horizontal circle parallel to the plane on which the man is standing. The user will provide the height and radius of the circle.

9. Points generated on an overhead, quarter circle arc. The plane of the circle will include the Z-axis and make a user-supplied aspect angle with the XZ plane. Points will be picked from a user-chosen distribution. The two possible distribution functions are, (a) uniform, and (b) the sine of the polar angle of the radius vector of the point (see Figure 2).

The directions taken by the rays are picked from a user-selected choice of three different angular distributions. These distributions are:

1. Isotropic about the point of origin. In practice, the direction of the ray is usually chosen so that it falls within the solid angle subtended by the sphere enclosing the man box. A normalization factor, that is the quotient of the solid angle subtended by the sphere divided by 4π, is calculated and printed in the output.

2. Bivariate normal about the line from the ray origin to a user-supplied point within the man. This capability was provided to the code to simulate the marksmanship of an individual aiming a weapon toward a point on the man. The horizontal and vertical standard deviations of the marksman's efforts in degrees are provided by the user.

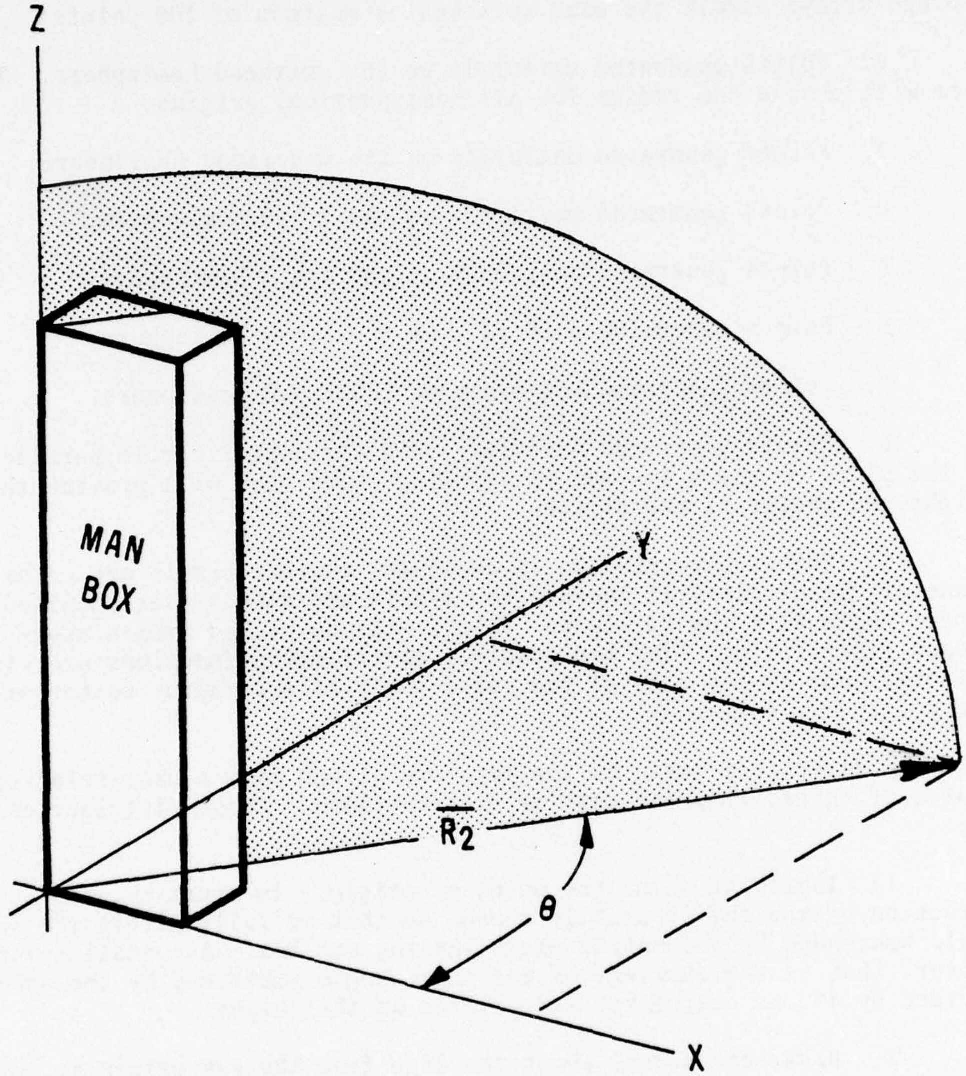


Figure 2. Typical Quarter-Circle Arc

3. User-supplied direction cosines. The code will automatically restrict the problem to one history per point when this option is exercised.

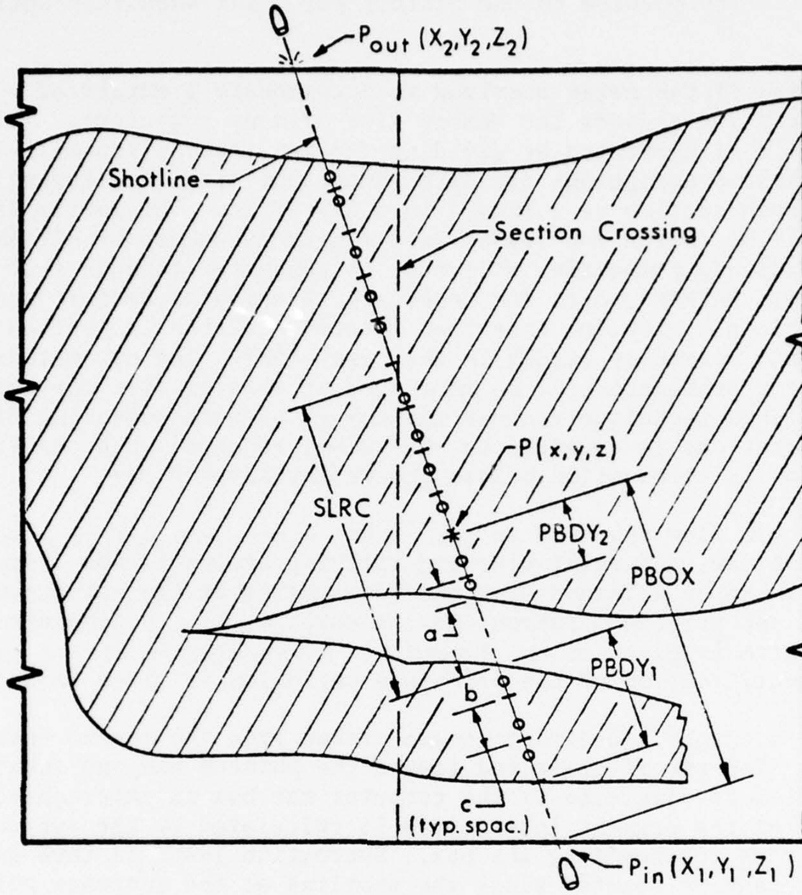
The size of the array required to accommodate a matrix of a complete description exceeds the memory size of many computers. This limitation is circumvented by dividing the man into horizontally-bounded sections whose descriptions are of a manageable size and storing the matrix of each section as a record in a disc file. The matrix of a section will be chosen and loaded into memory as needed by RAYMAN generated commands and promenades will then be conducted through that part of the phantom. RAYMAN stores the necessary tracking parameters when a promenade along a shotline enters an inactive section (a section whose matrix is not currently loaded in the array MAN). The parameters of such a latent promenade will be retrieved at a later time for further tracking. This technique reduces the number of time-consuming disk loading operations as compared to the number required when tracking each shotline to its termination before generating another ray.

The logic flow involved in generating a ray, conducting a promenade along a shotline, and retrieving and tallying scores is now discussed. More detail can be obtained from the flow charts of the main routine (Figure 4) and principle subroutines (Figures 5 -9). A complete listing of the program is given in the Appendix. A description of the subroutines and the identification of the principle variables is given in Section III.

A ray's origin and direction are picked from the chosen density functions. The ray is projected toward the phantom man and subroutine BOX is called to determine if the computer man box is intercepted. The length SLR of the segment intercepted is calculated by the subroutine for those rays intercepting the box. Subroutine TRACK is then entered and a promenade is started along the shotline at the entrance point of the ray if the section of the man being entered is the section whose matrix is currently stored in the array MAN. The promenade step width is set to the histogramic bin width when a promenade is started. The parameters of the promenade are stored in latent storage if the matrix stored in MAN does not belong to the section being entered.

The promenade is continued inside the box until tissue is encountered. The distance traversed through the box PBØX is incremented after each step and compared to SLR to determine if another full-width step in the box is possible. The distance to a section crossing SLRC is calculated by subroutine CRØSS to determine if another full width step in the active section is possible (see Figure 3).

The first score is made when the promenade enters tissue. The score is estimated stochastically when the complete length of that step is in tissue. This is accomplished by picking a point with equal probability at any site along the step and retrieving the M-value from the array MAN



$$SLR = \left[(X_2-X_1)^2 + (\overline{XL2}-0)^2 + (Z_2-Z_1)^2\right]^{\frac{1}{2}}$$

P(x,y,z) = Current Position Along Promenade.

$PBDY = \overline{PBDY_1} + \overline{PBDY_2}$

= Tissue.

o = Scoring Point.

= Sampling Step Width.

Figure 3. A Cross Section of the Computer Man that Contains a Shotline

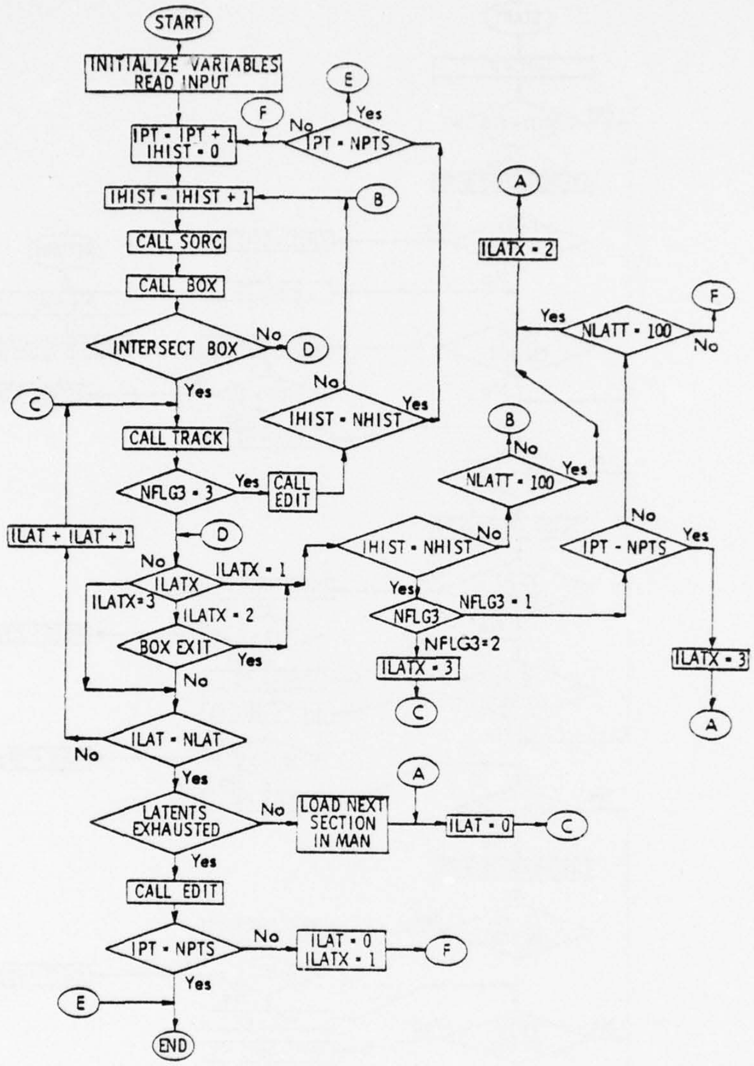


Figure 4. Main Routine

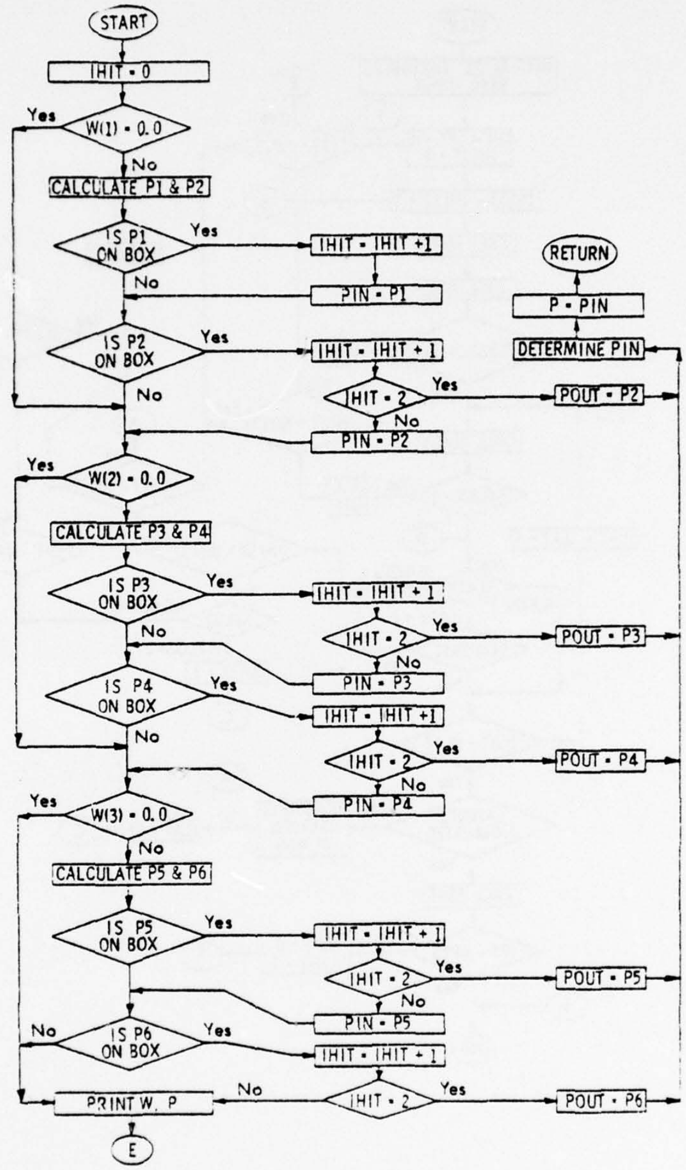


Figure 5. Box Subroutine

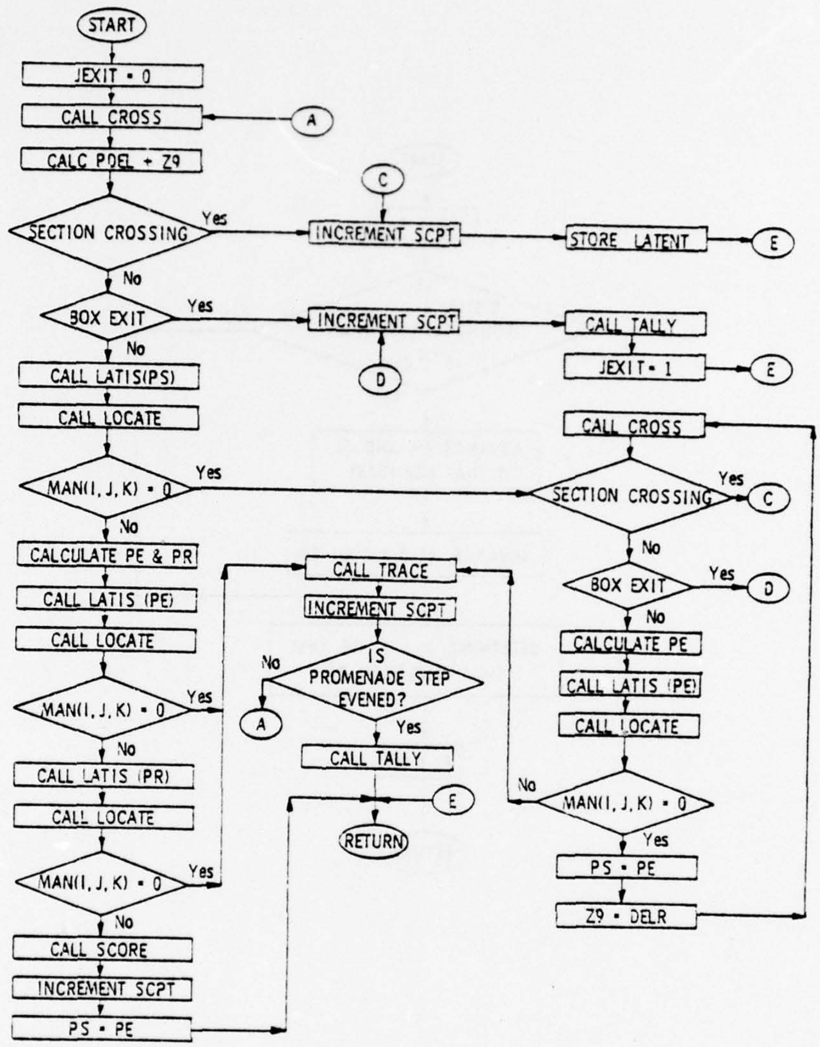


Figure 6. Even Subroutine

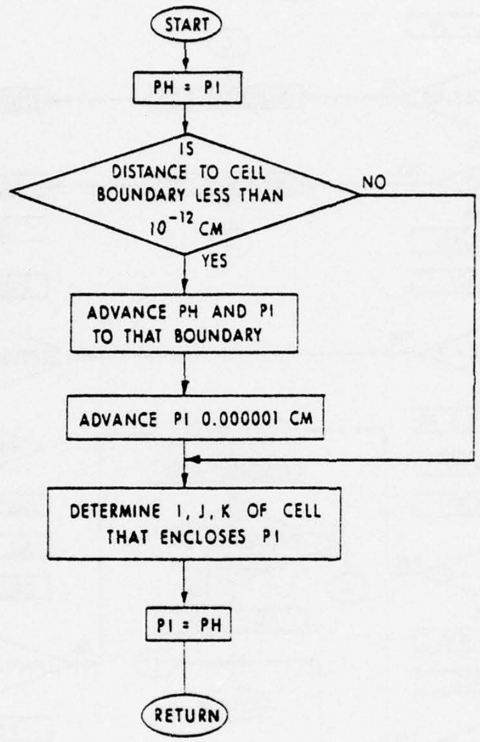


Figure 7. Latis Subroutine

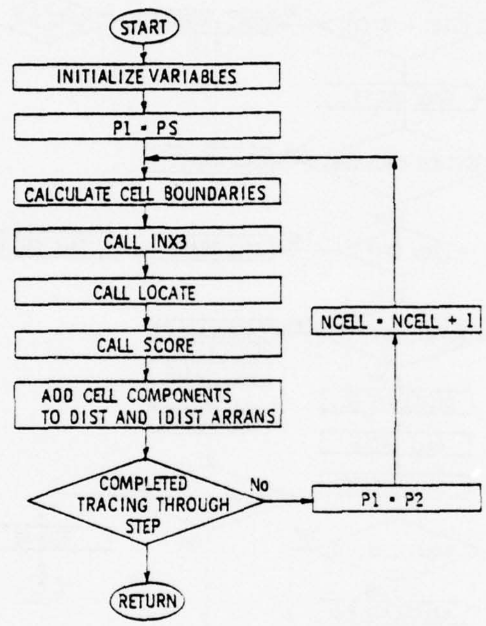


Figure 8. Trace Subroutine

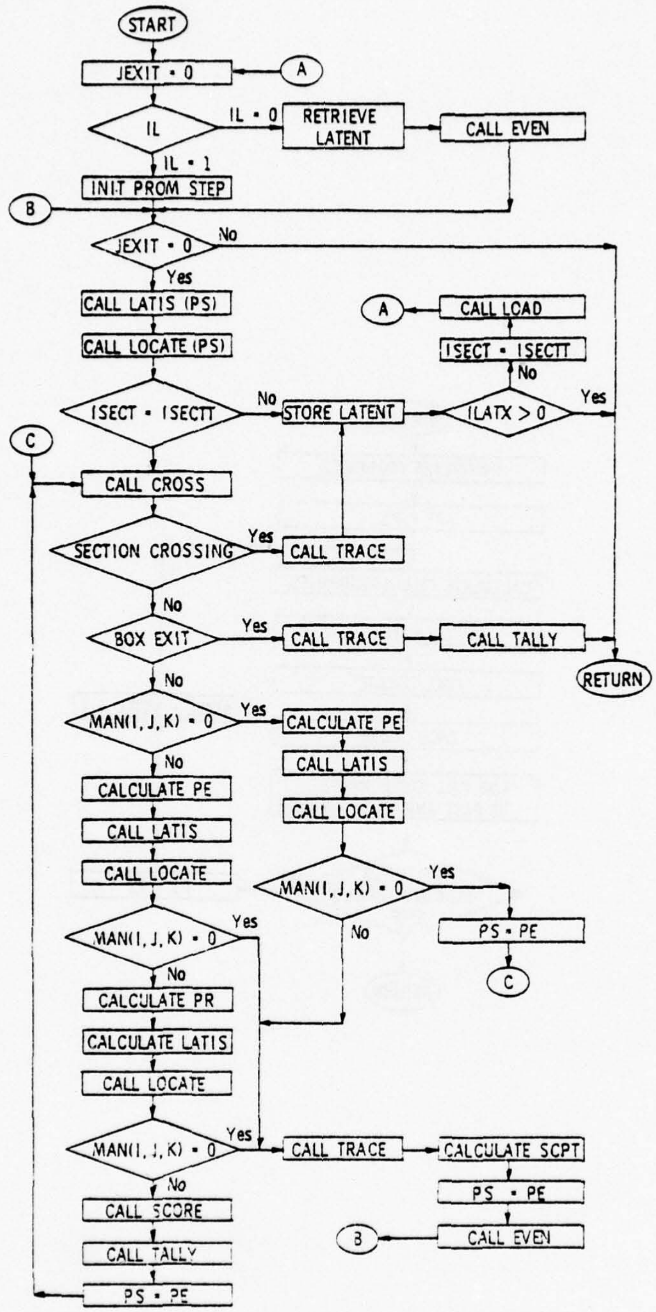


Figure 9. Track Subroutine

for the cell enclosing that point. This score is then added to the first bin of the array VI. The square of the score is added to the first bin of the V12 array. The array NVI, used to tally the number of promenades penetrating that amount of tissue, has its first bin incremented by one. The amount of tissue penetrated during the current promenade PBDY is set to the histogramic bin width DELR.

The score is calculated exactly when the promenade initially enters tissue and the entering step is only partially in tissue. The final score deposited in the VI-array will also be made for a tissue penetration depth of DELR but more than one promenade step will be needed to attain that penetration. A partial score SCPT is obtained for the tissue-entering step by calculating the product of the fraction of a bin width intercepted by a cell and the M-value of that cell and summing those products over all cells encountered along the step.

This is accomplished in the code by calling subroutine TRACE to calculate the necessary cell intercepts and to retrieve the necessary M-values. The intercept lengths are stored in DIST(1,m) and the M-values in DIST(2,m). A partial score SCPT is then calculated that is given by

$$\mathrm{SCPT} = \frac{1}{\mathrm{DELR}} \sum_{m=1}^{\mathrm{NCELL}} \mathrm{DIST}(1,m) \cdot \mathrm{DIST}(2,m) \tag{1}$$

where

NCELL = the number of cells intercepted during the step

m = the running index over cells intercepted.

The variable PBDY will be incremented by

$$\mathrm{PBDY} = \sum_{m=1}^{\mathrm{NCELL}} \mathrm{DIST}(1,m) \cdot H[\mathrm{DIST}(2,m) - \varepsilon] \tag{2}$$

where

$H[\mathrm{DIST}(2,m) - \varepsilon]$ = the Heaviside step function,

ε = a positive infinitesmal.

The variable PBØX will, as usual, be incremented by the full step width.

Subroutine EVEN is now called to calculate the partial score(s) of the additional step(s) needed to obtain a full bin width of tissue penetration. These latter score(s) may be estimated stochastically or calculated analytically as determined by the tissue or non-tissue status of

successive cells. The total score for a full bin-width of tissue penetration is added to the VI array and the other variables and arrays are properly incremented. The step width is then reset to DELR and a normal-gaited promenade through tissue is ready to be started.

That pace, conducted in subroutine TRACK, is maintained until the promenade exits the box or current section, or leaves tissue. A point is picked uniformly along each step and the M-value associated with the cell enclosing that point is retrieved from the array MAN and stored in the proper bin of the VI-array.

Subroutine TRACE is called again when checks predict that the next step will exit tissue. The variable values retrieved or calculated by TRACE are used to calculate a partial score SCPT, as described in Eq. 2 for the amount of tissue penetrated during the step. Subroutine EVEN is then entered and the promenade is continued until tissue is re-entered (or the box is exited or a new section is entered). The partial score for a segment of a length sufficient to complete the bin is calculated when tissue is reencountered and is added to the previously calculated partial score. The total score is added to the proper VI bin, all variables are updated, and control of the promenade is returned to subroutine TRACK where a normal gait is resumed.

The partial score will always be calculated for the last step of a promenade in the box (regardless of whether that step was encountered in subroutine TRACK or EVEN). The partial score is calculated in the customary manner, normalized to a full bin width, in a statistically valid way, and added to the proper VI bin.

The partial score will always be calculated for the last step before a section crossing. SCPT is calculated in the usual manner and placed in latent storage along with the other necessary parameter values. Subroutine LATENT performs this storage as well as the later retrieval.

The parameter values for 100 promenades can be stored as latents. The flag ILATX is used to direct the storage and retrieval of these parameters. ILATX is set to 1 at the beginning of each editing unit of histories. It remains at this value until latent storage is saturated or all promenades required by the current editing group have been started. This value of 1 directs the code to store latents when necessary but to not yet retrieve latents.

ILATX is set to 2 when the parameters for the 100 latent promenades have been stored and will remain at that value until all histories requested by the current editing group have been started. This mode orders the retrieval of the next latent promenade that is entering the currently loaded section of the man when the tracking of the previous promenade (either latent or virgin) ended in a section crossing, with a subsequent

latent storage. A box exit of the previous promenade will, on the other hand, return a space for the potential storage of a new latent that is derived from a presently unstarted promenade. New rays may therefore be generated and their promenades conducted until one of them has to be stored as a latent.

The sweep of the latent storage arrays for retrieving latent promenades entering the currently loaded section of the man is started when ILATX is set to 2. The VI-matrix of the section having the most latent promenades making an entrance, is loaded into MAN at the completion of a sweep and a new sweep will be initiated.

ILATX is set to 3 when all histories in an editing group have been started. New rays will not be generated and latent promenades will be retrieved and tracked until latent storage is exhausted. Restorage of a latent promenade after its retrieval and tracking is possible in this as well as the preceding mode of ILATX.

The editing of results may be implemented in the ends of each history, at the end of each group of histories emanating from a point, or at the end of a run. The mean of the score and its standard deviation are calculated for each bin. These values, as well as the number of promenades penetrating that amount of tissue, are printed in tabular form along with identifying captions.

III. SUBROUTINES AND VARIABLES

A. Subroutine Descriptions

1. Driver Routine. This routine reads in the user-supplied data and instructions. Once calculated values of variables are derived, before entering the ray-generating cycle, the ILATX-routing to different modes of operation and choosing of VI-matrices for loading into the array MAN are also conducted in this routine.

2. Subroutine AD. This routine directs the logic flow to the user-chosen ray angular distribution.

3. Subroutine ARC. This subroutine picks an origin for the ray on an overhead, quarter-circle arc. These points may be picked from two distributions. The distributions are: (a) uniform, and (b) sine of the polar angle of the point.

4. Subroutine BIVAR. This subroutine picks the direction of a ray from a bivariate normal distribution about the line from the ray origin to a user-supplied point usually (but not necessarily) located in the man. The vertical and horizontal standard deviations of the marksman are supplied by the user.

5. Subroutine BOX. The man is assumed to be barely enclosed by a rectangular box. This subroutine will project the current ray toward the box and calculate the length SLR of the segment intercepted. The coordinates of the entering point of the ray are also returned to be used as the start of the promenade.

6. Subroutine CHECK. The Computer Man description is double-valued on the cell boundaries. Subroutine CHECK inspects rays to determine if they will travel on these boundaries. A ray that would have such a path will have the critical coordinate of its origin randomly translated by a small amount so that its path will not lie on a cell boundary.

7. Subroutine CRØSS. This subroutine is used to calculate the distance from the beginning of the current promenade step to the nearest z boundary. This distance SLRC is returned to the main program.

8. Subroutine EDIT. This subroutine directs the calculation of the mean and standard deviations of accumulated scores. It will also print the results in tabular form along with identifying captions.

9. Subroutine EVEN. This subroutine is called by subroutine TRACK after a promenade has entered (or reentered) tissue or has been revived after storage as a latent. The promenade gait will be brought into phase with the histogramic bin structure of tissue penetration. Subroutines SCORE and TALLY are called in this subroutine.

10. Subroutine HEMI. This subroutine picks a ray-origin point uniformly on any of the user-chosen hemispheres.

11. Subroutine INX3. This subroutine calculates the distance from a point on a shotline in a cell to the exit of the shotline from the cell. This distance, as well as the exit point, are returned to subroutine TRACE for use in calculating partial scores.

12. Subroutine ISOT. This subroutine is used to pick the direction of a ray uniformly about its origin. In practice, the wasteful practice of picking directions for rays that would not intercept the man is improved by picking directions that will project a ray within the solid angle subtended by a sphere barely enclosing the man box. A normalization factor that is the ratio of this solid angle to 4π is calculated so that the user may calculate absolute probabilities. The direction parameters are converted to direction cosines and the latter quantities are returned to the main program.

13. Subroutine LATENT. This subroutine is called to store or retrieve latent promenades. The 0 or 1 value of the first variable IL in the argument directs toward a retrieval or a storage respectively.

14. Subroutine LATIS. This subroutine locates the cell that encloses the point PI. The x-axis index (I1), y-axis index (J1), and z-axis index (K1) are returned. The I, J, and K indices are derived from I1, J1, and K1 and are used in their place for retrieving scores so that program abortion caused by truncation approximation will be avoided at the box boundaries. A point on a shotline that lies on a cell boundary will be assumed to lie within the cell being entered.

15. Subroutine LOAD. The principal function of this subroutine is to load the VI-matrix of a chosen section into the array MAN from disc. A secondary role is to call subroutine TEST to generate a test MAN array when requested by the user.

16. Subroutine LOCATE. The role of this subroutine is to determine the section of the Computer Man that includes the z-axis index KP (absolute). This index is then converted to its value relative to the bottom of that section and returned as KP (relative).

17. Subroutine SCORE. This subroutine retrieves the score from MAN(I,J,K). The score is returned in both fixed point and floating point mode. It is anticipated that this subroutine may be rewritten as required by other forthcoming descriptions of the Computer Man.

18. Subroutine SORC. This subroutine provides the routing to the chosen ray-generating routines. It will also calculate the distance from the ray origin to the center of the box or to the aiming point in the man.

19. Subroutine TALLY. This subroutine will add the score that was estimated or calculated to that already accumulated in the proper bin in the VI array. The bin of the array that tallies the number of shotlines reaching that penetration in tissue NVI is also incremented by 1. The square of the score is added to the VI2 array to be used at the completion of the editing group to calculate standard deviations.

20. Subroutine TEST. This subroutine is used to build a test pattern of scores in the MAN array. It can be easily rewritten to satisfy the needs of the user.

21. Subroutine TRACE. This subroutine is used to advance a distance R along a shotline while calculating the distances penetrated in intercepted cells and retrieving the scores in these cells. The number of cells in which the segment R lies is also calculated and returned as NCELL.

22. Subroutine TRACK. This subroutine initiates the promenade along a newly-generated shotline or resumes the promenade along a retrieved latent shotline. Subroutine EVEN is called when needed to bring the promenade in phase with the histogramic bin structure. TRACK will conduct an even-gaited pace at other times (except for box-, section-,

or tissue-exits) with stochastic estimation of scores. TRACK will also calculate partial scores for the noted exceptions to the even gait when the preceding step was in TRACK.

23. Subroutine TRANS. The Computer Man box is assumed to be placed entirely in the first Cartesian octant with a corner located at the axis-origin. The RAYMAN subroutines that pick ray origins will use quarter-circles or spheres that are centered at the origin. This subroutine will translate the ray-origins, after being picked, so that they will lie on circles of spheres centered at the center of the man box.

24. Subroutine VAR. This subroutine calculates the standard deviation of each scoring bin.

B. Variable Description

1. BULSI(3). The coordinates of the aiming point in the Computer Man. It is used only when the bivariate normal angular distribution is used.

2. BKPT. The height at which the thickness of the slices changes.

3. DELR. This is the width of the histogramic bins in which scores are accumulated. DELR is also the preferred step width of the promenade through tissue.

4A. DIST(2,IZ). The score retrieved in the IZth cell tracked by subroutine TRACE.

4B. DIST(1,IZ). The length of the segment intercepted by the IZth cell in the tracking by subroutine TRACE.

5A. FACT(I) I=1,10. An adjustment factor for quantizing a ranking in the VI-matrix. All elements in FACT are currently set to unity.

5B. FACT(11). This element of FACT is set to 1.0 and is used in calculating partial scores.

6. GCH. The height of the great circle above the plane = 0.

7. GCR. The radius of the great circle about the vertical axis of the Computer Man.

8A. GRID(I) I=1,2. The x- and y-cell width of the Computer Man.

8B. GRID(3). The z-cell width of the lower part of the Computer Man.

8C. GRID(4). The z-cell width of the upper part of the Computer Man.

9. I. The x-axis cell index of the Computer Man. This quantity is adjusted at the box boundaries to prevent computer truncation approximations from causing the logic errors that would lead to incorrect answers or run abortion.

10. I1. The same as I for internal cells but it is not adjusted at the box boundaries.

11. IBKPT. The z-axis of the top slice of cells possessing a thickness of GRID(3).

12. IDIST(IZ). The fixed point score in the IZth cell tracked in subroutine TRACE.

13. IHIST. The running index for the rays generated from a point.

14. IHIT. The number of interceptions made in the walls of the Computer Man box by the ray.

15. ILAT. The running index for the retrieval of latent promenades.

16. ILATX. The flag for directing latent promenade storage and retrieval. The value ILATX = 1 directs toward storage only. The value ILATX = 2 permits either storage or retrieval. The value ILATX = 3 permits retrieval only.

17. IPT. The running index for the ray origin point.

18. ISECT. The current section of the Computer Man stored in the array MAN.

19. ISECTT. The section of the Computer Man in which a designated point is located.

20. ISEED. A fixed point number used as an argument by the (0,1) random number generator.

21. ISL. The maximum number of horizontal slices of the Computer Man stored in a section. This number is the same for all sections except possibly the topmost section.

22. ISC. The fixed point value of the score in a cell.

23. J. The y-axis cell index of the Computer Man. This quantity is adjusted at the box boundaries to allow for computer truncation approximations.

24. J1. The same as J for internal cells but it is not adjusted at the box boundaries.

25A. JLAT(1,IP). The section number into which the IPth latent promenade is entering.

25B. JLAT(2,IP). The number of histogramic bins into which scores have been tallied for the IPth latent promenade.

26. JSEED. The fixed point argument for generating a pair of random numbers picked from a normal distribution.

27. JEXIT. A flag showing that a cell of subroutine EVEN has led to a box exit by the current promenade.

28. K. The z-axis cell index of the Computer Man. This quantity is adjusted at the box boundaries to allow for computer truncation approximations during calculations along the promenade.

29. KI. The same as K for internal cells but it is not adjusted at the box boundaries.

30. MAN(I,J,K). The array used to store the incapacitation input data for the current section of the Computer Man.

31. NARC. A flag for choosing the distribution from which an origin point of a ray on the quarter-circle is picked. The value NARC = 0 leads to picking by a distribution given by the sine of the polar angle while the value NARC = 1 leads to picking a point uniformly on the arc.

32. NCELL. The number of cells penetrated by the shotline segment when subroutine TRACE is used.

33. NDEL. The number of histogramic bins into which scores have been added for the current promenade.

34. NFACT. A flag for determining if FACT values are to be read in as part of the input or if the values are to be defaulted to 1.0.

35. NFLG1. A flag for determining the distribution from which ray origins will be picked. The options are discussed in the user-supplied input section of this report.

36. NFLG2. A flag for determining the distribution from which ray directions are chosen. The options are discussed in the user-supplied input section of this report.

37. NFLG3. The flag for determining the editing group to be used. The options are discussed in the user-supplied input section of this report.

38. NHIST. The number of rays to be started at a point.

39. NHITS. The number of rays intercepting the Computer Man for an editing group.

40. NLAT(ISECT). The number of latent promenades that are entering section ISECT.

41. NLATT. The number of latent promenades stored.

42. NLOAD. The number of times that a different VI-matrix was loaded into MAN.

43. NPTS. The number of points from which rays are to be started.

44. NSECT. The number of sections into which the Computer Man is divided.

45. NTEST. A flag to determine if test values are to be generated for the array MAN.

46. NVI(I) I=1,200. The counter for determining the number of shotlines that have penetrated a distance in tissue greater than (I-1) ·DELR.

47. NX. The number of Computer Man cells in the x-direction.

48. NY. The number of Computer Man cells in the y-direction.

49. NZ. The number of Computer Man cells in the z-direction.

50. P(I) I=1,3. The coordinates of the ray origin.

51. PBDY. The distance in tissue penetrated during a promenade.

52. PBØX. The distance in the man box penetrated during a promenade.

53. PC(I) I=1,3. The coordinates of the point at which a promenade will cross the next section boundary.

54A. PLAT(1,IP). The initial value of PBDY for the IPth latent.

54B. PLAT(2,IP). The initial value of PBØX for the IPth latent.

54C. PLAT(3,IP). The value of SLR for the IPth latent.

55. PS(I) I=1,3. The coordinates of the beginning of the step in a promenade.

56. PR(I) I=1,3. The coordinates of the uniformly-picked point on a promenade step.

57. PE(I) I=1,3. The coordinates of the end of the step in a promenade.

58. PTAR(I,IP) I=1,3. The coordinates of the beginning of the IPth latent promenade or the coordinates of the origin of a user-provided ray.

59. PTAR(I,IP) I=4,6. The direction cosines of the shotline or ray described in item 58.

60. P1(I), P2(I), I=1,3. The coordinates of the intersection of the ray with the X=0 and X=XL3 plane respectively. This usage occurs in subroutine BOX.

61. P3(I), P4(I), I=1,3. The coordinates of the intersection of the ray with Y=0 and Y=XL2 plane respectively. This usage occurs in subroutine BOX.

62. P5(I), P6(I) I=1,3. The coordinates of the intersection of the ray with the Z=0 and Z=XL3 plane respectively. This usage occurs in subroutine BOX.

63. P1(I), P2(I). These arrays are also used in subroutines TRACE and INX3 to store the coordinates of the start or entrance of a segment into a cell and its termination or exit from the cell.

64. PDEL. The amount of tissue penetrated in a new bin. This variable is used in subroutine TRACK.

65. PL1. This variable is used in subroutine TRACE and INX3. The plane X=PL1 includes one side of the cell which could be the exit boundary of the shotline from the cell.

66. PL2. This variable is used in subroutine TRACK and TRACE. The plane Y=PL2 includes another side of the cell which could be the exit boundary of the shotline from the cell.

67. PL3. This variable is used in subroutine TRACK and TRACE. The plane Z=PL3 includes a third side of the cell which could be the exit boundary of the shotline from the cell.

68. R1. The radius of the sphere that barely encloses the Computer Man box.

69. R2. The distance from the ray origin to the center of the man box. It is also used as the distance from the ray origin to the point BULSI.

70. SCPT. A partial score that is calculated exactly when a promenade is being brought into phase with the histogramic bin structure.

71. SD1. The standard deviation (degrees) in the vertical direction of the shots triggered by a marksman.

72. SD2. The standard deviation (degrees) in the horizontal direction of the shots triggered by a marksman.

73. SLR. The length of the segment of the ray intercepted by the Computer Man box.

74. SPCT. The ratio of the solid angle subtended by the Computer Man box sphere to 4π.

75. SLRC. The distance from the beginning of a step to a section crossing. This variable is defaulted to 2,000,000 when W(3) = 0.0.

76. SPLT. An array for storing the heights of the section boundaries. The values are stored in ascending order.

77. SC. The floating-point score.

78. VI(1P). The bin for accumulating VI scores whose penetration in tissue is between (IP-1)* DELR and IP* DELR.

79. VI2(1P). The array for storing the square of the scores deposited in the VI array.

80. W(IZ), IZ=1,3. An array for storing the direction cosines of the current ray.

81. WP(IZ), IZ=1,3. An array for storing the direction cosines of the line from the ray origin to either the aiming point (BULSI) or the center of the Computer Man box.

82. XL1. The plane X=XL1 is an outside boundary of the Computer Man box.

83. XL2. The plane Y=XL2 is an outside boundary of the Computer Man box.

84. XL3. The plane Z=XL3 is an outside boundary of the Computer Man box.

85. Z9. The length of the part of a segment of the shotline that is in the current cell. This variable name is used in subroutine TRACE and INX3.

IV. RAYMAN INPUT

1. TITLE

A maximum of 80 alphanumeric identifying characters.

(8A10).

2. ISEED , JSEED
ISEED = (0.1) random number routing argument.
JSEED = normal random number routine argument (2I10).

3. NTEST, NFACT, NARC

NTEST = Flag for generating test numbers for the MAN array.

NTEST = 1, generates numbers for MAN.
NTEST = 0, loads data from disc to MAN.

NFACT = Flag for filling the FACT array.

NFACT = 0, reads in user-chosen numbers.
NFACT = 1, all elements in FACT are defaulted to unity.

NARC = Flag to determine distribution of ray origins on the quarter circle.

NARC = 0, points are picked from the sine of the polar angle. distribution.
NARC = 1, points are picked uniformly along the arc.

(10I5)

4. NFLG1, NFLG2, NFLG3, NPTS, NHIST

NFLG1 = Ray origin flag.

NFLG1 = 1, read in points.
= 2, uniformly distributed on the upper hemisphere.
= 3, uniformly distributed on the lower hemisphere.
= 4, uniformly distributed on the front hemisphere.
= 5, uniformly distributed on the back hemisphere.
= 6, uniformly distributed on the right hemisphere.
= 7, uniformly distributed on the left hemisphere.
= 8, uniformly distributed on the great circle.
= 9, distributed on quarter-circle arc.

NFLG2 = Ray direction flag.

NFLG2 = 1, isotropic angular distribution.
= 2, bivariate normal angular distribution.
= 3, read in directions.

NFLG3 = Editing group flag.

NFLG3 = 1, composite editing group.
      = 2, each point editing group.
      = 3, each history editing group.

NPTS = Number of ray origin points.

NHIST = Number of rays per point.

(10I5)

5. NX, NY, NZ, IBKPT, ISECT, NSECT

NX = Number of x-axis cell boundaries in box.

NY = Number of y-axis cell boundaries in box.

NZ = Number of z-axis cell boundaries in box.

IBKPT = Number of z-axis cells up to slice thickness change.

ISECT = Initial section of the man loaded into MAN.

NSECT = Number of sections.

(10I5)

6. ISL

ISL = Number of slices per section (except for possibly the topmost section).

(10I5)

7. GRID(I), I=1,4 DELR

GRID(1) = x-axis cell width (cm).
GRID(2) = y-axis cell width (cm).
GRID(3) = z-axis lower cell width (cm).
GRID(4) = z-axis upper cell width (cm).
DELR = promenade step width (cm).

(6E10.3)

8A. IF NFLG1 = 1, provide

PO(I), I=1,3; WC(I), I=1,3   IF NPTS=1

PTAR(I,IPT) I=1,6   IF NPTS>1

PO(1) or PTAR(1,IPT) = x-coordinate of ray origin

PO(2) or PTAR(2,IPT) = y-coordinate of ray origin

PO(3) or PTAR(3,IPT) = z-coordinate of ray origin

W(1) or PTAR(4,IPT) = x-axis direction cosine of ray

W(2) or PTAR(5,IPT) = y-axis direction cosine of ray

W(3) or PTAR(6,IPT) = z-axis direction cosine of ray

(6E10.3)

8B. IF NFLG1 = 2-7, provide

R2
R2 = radius of hemisphere

(6E10.3)

8C. IF NFLG1 = 8, provide

GRC, GCH
GRC = Radius of circle (cm).
GCH = Height of circle above z=0

(6E10.3)

8D. IF NFLG1 = 9, provide

R2, THETA
R2 = Radius of arc (cm)
THETA = azimuth angle (degrees) with x-axis

(6E10.3)

9. IF NFLG2 = 2, provide

SD1, SD2
SD1 = azimuthal standard deviation (degrees) of the marksman.
SD2 = elevation standard deviation (degrees) of the marksman.

(6E10.3)

10. IF NFLG2 = 2, provide

BULSI(I) I=1,3
BULSI(1) = x-coordinate of aiming point
BULSI(2) = y-coordinate of aiming point
BULSI(3) = z-coordinate of aiming point

(6E10.3)

11. IF NFACT = 0, provide

FACT(I) I=1,10
FACT(1) = adjustment for VI = 1
.
.
.
FACT(10) = adjustment factor for VI = 10
FACT(11) = 1.0 always

(6E10.3)

V. TEST PROBLEM

The input needed for a test problem is given in Table I. This data is presented in the format in which it is printed in the output by the computer. The output average VI-Scores of this test problem is presented in Table II.

VI. CONCLUSIONS

The RAYMAN Computer Code has been run successfully on the BRLESC computer. Readers desiring a copy of the code may send a blank magnetic tape to the Target Assessment Branch, Vulnerability/Lethality Division, ATTN: DRDAR-BVL, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland 21005. Users are cautioned that the BRLESC names of certain library routines may not agree with those used by other computer facilities and will need to be changed.

Table I. Sample Input

```
     UPPER HEMISPHERE TESR
ISEED =      11111111  JSEED =      11113111
NTEST =         1      NFACT =         1
NARC=           1
 NO PTS =     100      NO HIST =       1
ILATX =         1
NFLG1 =         2      NFLG2 =         1     NFLG3 =       1
NO X'S =      110      NO Y'S =       55     NO Z'S =     84
IBKPT =        64      SECT NO =       2     NO SECT =    14     NO SLICE =    5
X-CELL =   0.5000E 00     Y-CELL =   0.5000E 00     Z1-CELL =  0.2600E 01     Z2-CELL =  0.1200E 01
R-INCREM = 0.1000E 01
SOURCE-X = 0.0000E 00     SOURCE-Y = 0.0000E 00     SOURCE-Z = 0.0000E 00
X-DIR CS = 0.0000E 00     Y-DIR CS = 0.0000E 00     Z-DIR CS = 0.0000E 00
BOX-RAD =  0.1000E 03     PT-RAD =   0.1000E 04
X-SIDE =   0.5500E 02     Y-SIDE =   0.2750E 02     Z-SIDE =   0.1904E 03

FACT MAT =   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
BELT RAD = 0.0000E 00     BELT HGT = 0.0000E 00
BULSI(1) = 0.0000E 00     BULSI(2) = 0.0000E 00     BULSI(3) = 0.0000E 00
GREAT CIRCLE SU-ANGLE= .000000E 00
GREAT CIRCLE CS-ANGLE= .000000E 00
HOR SD =   0.0000E 00     VERT SD =  0.0000E 00
H-GW FCT = 0.0000E 00     V-GW FCT = 0.0000E 00
```

Table II. Sample Output

INCREMENT			VUL INDEX		STAND DEV			NO RAYS
1*	*	*	0.7000E 01	+-	0.3980E 01*	*	*	20
2*	*	*	0.7150E 01	+-	0.3392E 01*	*	*	20
3*	*	*	0.7150E 01	+-	0.2756E 01*	*	*	20
4*	*	*	0.7300E 01	+-	0.2519E 01*	*	*	20
5*	*	*	0.7201E 01	+-	0.2559E 01*	*	*	20
6*	*	*	0.6765E 01	+-	0.2990E 01*	*	*	17
7*	*	*	0.6588E 01	+-	0.3483E 01*	*	*	17
8*	*	*	0.6647E 01	+-	0.3605E 01*	*	*	17
9*	*	*	0.7200E 01	+-	0.2931E 01*	*	*	15
10*	*	*	0.6857E 01	+-	0.3207E 01*	*	*	14
11*	*	*	0.8077E 01	+-	0.2290E 01*	*	*	13
12*	*	*	0.7231E 01	+-	0.2242E 01*	*	*	13
13*	*	*	0.8154E 01	+-	0.2444E 01*	*	*	13
14*	*	*	0.8417E 01	+-	0.2392E 01*	*	*	12
15*	*	*	0.7818E 01	+-	0.2892E 01*	*	*	11
16*	*	*	0.7571E 01	+-	0.3452E 01*	*	*	11
17*	*	*	0.7823E 01	+-	0.3629E 01*	*	*	10
18*	*	*	0.8111E 01	+-	0.3257E 01*	*	*	9
19*	*	*	0.7703E 01	+-	0.3339E 01*	*	*	9
20*	*	*	0.9000E 01	+-	0.1927E 01*	*	*	[illegible]
21*	*	*	0.9250E 01	+-	0.1753E 01*	*	*	[illegible]
22*	*	*	0.8750E 01	+-	0.2319E 01*	*	*	8
23*	*	*	0.8522E 01	+-	0.3149E 01*	*	*	[illegible]
24*	*	*	0.9571E 01	+-	0.1134E 01*	*	*	7
25*	*	*	0.9286E 01	+-	0.1379E 01*	*	*	7
26*	*	*	0.7714E 01	+-	0.4071E 01*	*	*	7
27*	*	*	0.7357E 01	+-	0.3388E 01*	*	*	7
28*	*	*	0.7714E 01	+-	0.3392E 01*	*	*	7
29*	*	*	0.7571E 01	+-	0.3359E 01*	*	*	7
30*	*	*	0.7000E 01	+-	0.3638E 01*	*	*	6
31*	*	*	0.8000E 01	+-	0.2739E 01*	*	*	5
32*	*	*	0.8000E 01	+-	0.3082E 01*	*	*	5
33*	*	*	0.7000E 01	+-	0.3606E 01*	*	*	3
34*	*	*	0.6709E 01	+-	0.4851E 01*	*	*	2
35*	*	*	0.1000E 02	+-	0.0000E 00*	*	*	2
36*	*	*	0.1000E 02	+-	0.1738E-06*	*	*	2
37*	*	*	0.1000E 02	+-	0.9990E 01*	*	*	1
38*	*	*	0.1000E 02	+-	0.9990E 01*	*	*	1
39*	*	*	0.1000E 01	+-	0.9990E 01*	*	*	1
40*	*	*	0.2000E 01	+-	0.9990E 01*	*	*	1
41*	*	*	0.2000E 01	+-	0.9990E 01*	*	*	1
42*	*	*	0.3000E 01	+-	0.9990E 01*	*	*	1
43*	*	*	0.4000E 01	+-	0.9990E 01*	*	*	1
44*	*	*	0.5000E 01	+-	0.9990E 01*	*	*	1
45*	*	*	0.6000E 01	+-	0.9990E 01*	*	*	1

ACKNOWLEDGEMENT

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APPENDIX

RAYMAN LISTING

```
C       PROGRAM RAYMAN
        DIMENSION TITLE(8)

        COMMON/MANN/MAN(110,55,6),NTEST
        COMMON/LATEN/JLAT(2,100),NLAT(20),ILAT,NLATT,ISECT,ILATX,ISECTT,
       * PLAT(4,100),PTAR(6,100),PHDY,PROX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
        COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
        COMMON/POINT/PS(3),PR(3),PE(3),PC(3),DELR,NFLG3
        COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
        COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
        COMMON/EVAL/VI(200),NVI(200),VI2(200),FACT(11)
        COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
       * SNT,CST
        COMMON/LAT/NX,NY,NZ,NSECT,ISL
        COMMON/LODE/NLOAD
  500   FORMAT(F10.1)
  501   FORMAT(8A10)
  502   FORMAT(10I5)
  503   FORMAT(6E10.3)
  504   FORMAT(1H )
  505   FORMAT(1H1)
  506   FORMAT(2I10)
  507   FORMAT(6(A10,I5,5X))
  508   FORMAT(4(A10,E11.4,5X))
  509   FORMAT(2A10,A3,E11.7)
  510   FORMAT(A10,A4,I5)
  511   FORMAT(A10,11(F9.4,1X))
  512   FORMAT(2(A10,I10,2X))
  513   FORMAT(19F10.5)
  514   FORMAT(19X,I2,4X,F10.5)
  515   FORMAT(6(E20.14),/,I20)
  516   FORMAT(3(E20.14))
        READ(5,501) TITLE
        READ(5,506) ISEED,JSEED
        READ(5,502)NTEST,NFACT,NARC
        READ(5,502)  NFLG1,NFLG2,NFLG3,NPTS,NHIST
        IF(NFLG2.EQ.3) NHIST = 1
        READ(5,502)  NX,NY,NZ,IBKPT,ISECT,NSECT
        READ(5,502) ISL
        READ(5,503) GRID,DELR
        IF(NFLG1.GT.1) GO TO 6
        IF(NPTS.GT.1)  GO TO 4
        READ(5,503) PO,W
        GOTO 9
    6   IF(NFLG1.LT.9) GO TO 5
        READ(5,503) R2,THETA
        THETA = 3.14159*THETA/180.0
        CST = COSF(THETA)
        SNT = SINF(THETA)
        GO TO 9
```


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```
    4 READ(5,503)  ((PTAR(I,J),I=1,6),J=1,NPTS)
      GOTO 9
    5 IF(NFL31.GT.7)  GO TO 8
      READ(5,503) R2
      GO TO 9
    8 READ(5,503)  GCR,GCH
      WRITE(6,504)
    9 IF(NFL32.NE.2) GO TO 10
      READ(5,503)  SD1,SD2,GW1,GW2
      READ(5,503)  BULSI
   10 IF(NFACT.EQ.0) GOTO 998
      DO 997 I=1,10
      FACT(I) = 1.0
  997 CONTINUE $ GOTO 996
  998 CONTINUE
      READ(5,503) FACT
  996 CONTINUE
      FACT(11) = 1.0
      BKPT = GRID(3)*FLOATF(IBKPT)
      XL1=GRID(1)*FLOATF(NX)
      XL2=GRID(2)*FLOATF(NY)
      XL3=BKPT+GRID(4)*FLOATF(NZ-IBKPT)
      R1 = (0.5*XL1)**2 + (0.5*XL2)**2 + (0.5*XL3)**2
      R1 = SQRTF(R1)
      J=0
      DO 777 I=1,NSECT
      J=J+ISL
      IF(J.GT.IBKPT) GO TO 776
      XJ=FLOATF(J)
      SPLT(I)=XJ*GRID(3)
      GO TO 777
  776 XJ=FLOATF(J-IBKPT)
      SPLT(I)=BKPT+(XJ)*GRID(4)
777   CONTINUE
      ILATX = 1
      WRITE(6,505)
      DO 778 I=1,NSECT
      WRITE(6,514)(I,SPLT(I))
  778 CONTINUE
      WRITE(6,501) TITLE
      WRITE(6,504)
      CAP1 = 10HISEED =    $CAP2 = 10HJSEED =
      WRITE(6,512) CAP1,ISEED,CAP2,JSEED
      WRITE(6,504)
      CAP1 = 10HNTEST =    $CAP2 = 10HNFACT =
      WRITE(6,507)CAP1,NTEST,CAP2,NFACT
      WRITE(6,504)
      CAP1 = 10HNARC=
      WRITE(6,507)CAP1,NARC
      WRITE(6,504)
```

```
CAP1 = 10H NO PTS = $CAP2 = 10HNO HIST =
WRITE(6,507)CAP1,NPTS,CAP2,NHIST
WRITE(6,504)
CAP1 = 10HILATX =
WRITE(6,507)CAP1,ILATX
WRITE(6,504)
CAP1 = 10HNFLG1 =    $CAP2 = 10HNFLG2 =    $CAP3 = 10HNFLG3 =
WRITE(6,507)CAP1,NFLG1,CAP2,NFLG2,CAP3,NFLG3
WRITE(6,504)
CAP1 = 10HNO X'S =   $CAP2 = 10HNO Y'S =   $CAP3 = 10HNO Z'S =
WRITE(6,507)CAP1,NX,CAP2,NY,CAP3,NZ
WRITE(6,504)
CAP1 = 10HIBKPT =    $CAP2 = 10HSECT NO = $CAP3 = 10HNO SECT =
CAP4 = 10HNO SLICE =
WRITE(6,507)CAP1,IBKPT,CAP2,ISECT,CAP3,NSECT,CAP4,ISL
WRITE(6,504)
CAP1 = 10HX-CELL =   $CAP2 = 10HY-CELL =   $CAP3 = 10HZ1-CELL =
CAP4  = 10HZ2-CELL =
WRITE(6,508)CAP1,GRID(1),CAP2,GRID(2),CAP3,GRID(3),CAP4,GRID(4)
WRITE(6,504)
CAP1 = 10HR-INCREM =
WRITE(6,508)CAP1,DELR
WRITE(6,504)
CAP1 = 10HSOURCE-X =$CAP2 = 10HSOURCE-Y =$CAP3 = 10HSOURCE-Z =
WRITE(6,508)CAP1,P0(1),CAP2,P0(2),CAP3,P0(3)
WRITE(6,504)
CAP1 = 10HX-DIR CS =$CAP2 = 10HY-DIR CS =$CAP3 = 10HZ-DIR CS =
WRITE(6,508)CAP1,W(1),CAP2,W(2),CAP3,W(3)
WRITE(6,504)
CAP1 = 10HBOX-RAD = $CAP2 = 10HPT-RAD =
WRITE(6,508)CAP1,R1,CAP2,R2
WRITE(6,504)
CAP1 = 10HX-SIDE =   $CAP2 = 10HY-SIDE =   $CAP3 = 10HZ-SIDE =
WRITE(6,508)CAP1,XL1,CAP2,XL2,CAP3,XL3
WRITE(6,504)
WRITE(6,504)
CAP1 = 10HFACT MAT =
WRITE(6,511)CAP1,FACT
WRITE(6,504)
CAP1 = 10HBELT RAD =$CAP2 = 10HBELT HGT =
WRITE(6,508)CAP1,GCR,CAP2,GCH
WRITE(6,504)
CAP1 = 10HBULSI(1) =$CAP2 = 10HBULSI(2) =$CAP3 = 10HBULSI(3) =
WRITE(6,508)CAP1,BULSI(1),CAP2,BULSI(2),CAP3,BULSI(3)
WRITE(6,504)
CAP1=10HGREAT CIRC$ CAP2=10HLE SN-ANGL$ CAP3=3HE=
*$ CAP4=10HLE CS-ANGL
WRITE(6,509)CAP1,CAP2,CAP3,SNT
WRITE(6,504)
WRITE(6,509) CAP1,CAP4,CAP3,CST
```

```
      WRITE(6,504)
      CAP1 = 10HHOR SD =  $CAP2 = 10HVERT SD =
      WRITE(6,508)CAP1,SD1,CAP2,SD2
      WRITE(6,504)
      CAP1 = 10HH-GW FCT =$CAP2 = 10HV-GW FCT =
      WRITE(6,508) CAP1,GW1,CAP2,GW2
      WRITE(6,504)
      WRITE(6,504)
      WRITE(6,504)
      WRITE(6,504)
      WRITE(6,504)
      WRITE(6,504)
    7 CALL LOAD(ISECT) $ NLOAD=1
    1 NLATT = 0
   11 IPT = 0
   12 IHIST = 0
   13 IPT = IPT + 1
   14 IHIST = IHIST + 1
    3 CALL SORC
   20 CALL BOX(IHIT)
      IF(IHIT.LT.2) GO TO 995
      CALL CHECK
      IF(NFLG3.LT.3) GO TO 21
      CALL LATIS(P,I,J,K)
      CALL LOCATE(K,ISECTT)
      CALL LATENT(1,IPT,P)
      NLATT=NLATT+1
      NLAT(ISECTT)=NLAT(ISECTT)+1
  994 ISECT = JLAT(1,IPT)
      IF(ISECT.EQ.0) GO TO 995
      CALL LOAD(ISECT) $ NLOAD = NLOAD + 1
      CALL TRACK(0)
      GO TO 994
   21 CALL TRACK(1)
  995 IF(NFLG3.GT.1) GO TO 103
      IF(IHIST.LT.NHIST) GO TO 108
      IF(IPT.EQ.NPTS)  GO TO 102
      IHIST = 0  $ IPT = IPT + 1
      GO TO 108
  102 ILATX = 3  $ GO TO 113
  103 IF(NFLG3.GT.2) GO TO 116
      IF(IHIST.LT.NHIST) GO TO 108
      GO TO 102
  108 IF(NLATT.LT.100) GO TO 14
      IF(ILATX.EQ.2)  GO TO 109
      ILATX = 2
  113 ILAT = 0
  114 ILAT = ILAT + 1
      IF(JLAT(1,ILAT).NE.ISECT)  GO TO 120
      CALL TRACK(0)
```

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```
      IF(ILATX.EQ.3)  GO TO 120
  109 IF(JLAT(1,ILAT).EQ.0)  GO TO 14
  120 IF(ILAT.LT.NLATT) GO TO 114
  115 NLAT(ISECT) = 0
      I=1$ ISECT=1
    2 I=I+1
      IF(NLAT(I).GT.NLAT(ISECT))ISECT=I
      IF(I.LT.NSECT)GOTO 2
      IF(NLAT(ISECT).EQ.0) GO TO 116
      CALL LOAD(ISECT)   $ NLOAD = NLOAD + 1
      GO TO 113
  116 CAP1 = 10HNO MAN HITS CAP2 = 4HS =
      WRITE(6,510)CAP1,CAP2,NVI(1)
      WRITE(6,504)
      CAP1 = 10HNORMALIZATS CAP2 = 10HION FACTORSCAP3 = 3H =
      WRITE(6,509)CAP1,CAP2,CAP3,SPCT
      WRITE(6,504)
      CAP1 = 10HISEED =    SCAP2 = 10HJSEED =
      WRITE(6,512) CAP1,ISEED,CAP2,JSEED
      WRITE(6,504)
      CAP1=10HNO DISC LOS CAP2=4HAD =
      WRITE(6,510)CAP1,CAP2,NLOAD
      CALL EDIT
      ILATX = 1
      NLATT = 0  $ NHITS = 0
220   IF(NFLG3.EQ.1) GO TO 117
      IF(NFLG3.GT.2) GO TO 999
      IF(IPT.EQ.NPTS) GO TO 117
      GO TO 12
  999 IF(IHIST.LT.NHIST) GO TO 14
      IF(IPT.LT.NPTS) GO TO 12
  117 STOP
98765 CONTINUE
98766 CONTINUE
      WRITE(6,517) SCHI,SCATT,NLOAD,NTEST,ILAT,NLATT,ISECT,ILATX,ISECTT
  517 FORMAT (2(E12.4,2X),7(I4,2X))
      WRITE(6,518) PBDY,PBOX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
  518 FORMAT(3(E12.4,2X),5(I5,2X))
      WRITE(6,519) GRID,BKPT,IBKPT,SPLT
  519 FORMAT(5(E10.2,2X),I4,E20.12,2X,/,6(E20.12,1X),/,6(E20.12,1X),/,
     *6(E20.12,1X))
      WRITE(6,520) PS,PR,PE,PC,DELR,NFLG3
  520 FORMAT(9(E12.4,1X),/,4(E12.4,1X),I4)
      WRITE(6,521) R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
  521 FORMAT(4(E12.4,1X),2(I4,2X),4(E12.4,1X))
      WRITE(6,522) SLR,XL1,XL2,XL3,NHITS,DIST,IDIST,NCELL
  522 FORMAT (4(E12.4,1X),I5,/,10(E12.4,1X),/,10(E12.4,1X),/,11(I5,1X))
      WRITE(6,523) FACT
  523 FORMAT(11(E12.4))
      WRITE(6,524) WP,W,P,PO,BULSI,SPCT,ISEED,JSEED
```

```
  524 FORMAT(6(E12.4,1X),/,6(E12.4,1X),/,4(E12.4,1X),2(I9,1X))
      WRITE(6,504)
      WRITE(6,525) NLAT
  525 FORMAT(10(2X,I5))
      WRITE(6,504)
      WRITE(6,525) JLAT
      WRITE(6,504)
      STOP
      END
C
C
      SUBROUTINE AD
      COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
      IF(NFLG2.GT.1) GOTO 2
      CALL ISOT
      GO TO 3
    2 CONTINUE
      IF(NFLG2.GT.2) GOTO 3
      CALL BIVAR
    3 RETURN
      END
C
C
      SUBROUTINE ARC(NARC)
COM   NARC = 1 IS UNIFORM, NARC = 0 IS ISOTROPIC IE COSINE WEIGHTED
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
      IF(NARC.EQ.0) GO TO 2
    1 X1=URAN31(ISEED)
      X2=URAN31(ISEED)
      X1S = X1**2 $ X2S = X2**2
      T=X1S+X2S
      IF(T.GT.1.0) GOTO 1
      SNPHI=2.0*X1*X2/T
      CSPHI=ABSF((X1S-X2S)/T)
      GOTO 3
    2 CONTINUE
      CSPHI = URAN31(ISEED)
      SNPHI = SQRTF(1.0 - CSPHI**2)
    3 CONTINUE
      P(3)=R2*CSPHI
      P(1)=R2*SNPHI*CST
      P(2)=R2*SNPHI*SNT
      RETURN
      END
C
C
      SUBROUTINE BIVAR
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
```

```
     * SNT,CST
      COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
      IF(WP(3).EQ.-1.0) GO TO 5
      IF(WP(3).EQ.1.0) GOTO 5
      IF(IPRIM.EQ.1) GOTO 1
      PSI=WP(3)
      PSI=ARCCOS(PSI)
      THET=WP(2)/SQRTF(1.0-WP(3)**2)
      THET=ARCCOS(THET)
      IPRIM=1
      SPCT=1.0
      SD1 = SD1*3.14159/180.0
      SD2 = SD2*3.14159/180.0
    1 CALL NRAN31(RNN1,RNN2,JSEED)
      DEL=SD2*RNN2
      RNN3=URAN31(ISEED)
      IF(RNN3.GT.0.5)DEL=-DEL
      PSIH=PSI+DEL
      W(3)=COSF(PSIH)
      DEL=SD1*RNN1
      RNN3=URAN31(ISEED)
      IF(RNN3.GT.0.5)DEL=-DEL
      THETH=THET+DEL
      SINT=SQRTF(1.0-WP(3)**2)
      W(2)=SINT*COSF(THETH)
      W(1)=SINT*SINF(THETH)
      WRITE(6,10) WP,W,P,RNN1,RNN2,THETH
   10 FORMAT(6(E10.3,2X))
    5 RETURN
      END
C
C
      SUBROUTINE BOX(IHIT)
      DIMENSION PIN(3),POUT(3),NPL(2)
      DIMENSION P1(3),P2(3),P3(3),P4(3),P5(3),P6(3)
      COMMON/SORS/WP(3),W(3),P(3),P0(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      IHIT=0
COM   P1 AND P2 ARE X=0 AND X=XL1 INTERCEPTS
      P1(1)=0.0 $ P2(1)=XL1
      IF(W(1).EQ.0.0) GOTO 1
      Z9=-P(1)/W(1)
      P1(2)=W(2)*Z9+P(2)
      P1(3)=W(3)*Z9+P(3)
      Z9=Z9+XL1/W(1)
      P2(2)=W(2)*Z9+P(2)
      P2(3)=W(3)*Z9+P(3)
COM   X=0 AND X=XL1 PLANES
COM   CHECK FOR BOX INTERCEPT
```

```
      IF(P1(2).GE.XL2.OR.P1(2).LE.0.0)GOTO 5
      IF(P1(3).GE.XL3.OR.P1(3).LE.0.0)GOTO 5
      IHIT=1 $ NPL(1)=1
      DO 100 I=1,3
      PIN(I)=P1(I)
  100 CONTINUE
    5 IF(P2(2).GE.XL2.OR.P2(2).LE.0.0)GOTO 201
      IF(P2(3).GE.XL3.OR.P2(3).LE.0.0)GOTO 201
      IHIT=IHIT+1
      DO 7 I=1,3
      IF(IHIT.EQ.2)GOTO 6
      PIN(I)=P2(I) $ NPL(1)=2 $ GOTO 7
    6 POUT(I)=P2(I) $ NPL(2)=2
    7 CONTINUE
  201 IF(IHIT.EQ.2)GOTO 20
COM   P3 AND P4 ARE Y=0 AND Y= XL2 INTERCEPTS
    1 P3(2)=0.0 $ P4(2)=XL2
      IF(W(2).EQ.0.0) GOTO 3
      Z9=-P(2)/W(2)
      P3(1)=W(1)*Z9+P(1)
      P3(3)=W(3)*Z9+P(3)
      Z9=Z9+XL2/W(2)
      P4(1)=W(1)*Z9+P(1)
      P4(3)=W(3)*Z9+P(3)
COM   Y=0 AND Y=XL2 PLANES
      IF(P3(1).GE.XL1.OR.P3(1).LE.0.0) GOTO 10
      IF(P3(3).GE.XL3.OR.P3(3).LE.0.0) GOTO 10
      IHIT=IHIT+1
      DO 101 I=1,3
      IF(IHIT.EQ.2)GOTO 9
      PIN(I)=P3(I) $ NPL(1)=3 $ GOTO 101
    9 POUT(I)=P3(I) $ NPL(2)=3
  101 CONTINUE
   10 IF(P4(1).GE.XL1.OR.P4(1).LE.0.0) GOTO 202
      IF(P4(3).GE.XL3.OR.P4(3).LE.0.0) GOTO 202
      IHIT=IHIT+1
      DO 12 I=1,3
      IF(IHIT.EQ.2)GOTO 11
      PIN(I)=P4(I) $ NPL(1)=4 $ GOTO 12
   11 POUT(I)=P4(I) $ NPL(2)=4
   12 CONTINUE
  202 IF(IHIT.EQ.2)GOTO 20
COM   P5 AND P6 ARE Z=0 AND Z=XL3 INTERCEPTS
    3 P5(3)=0.0 $ P6(3)=XL3
      IF(W(3).EQ.0.0) GO TO 203
      Z9=-P(3)/W(3)
      P5(1)=W(1)*Z9+P(1)
      P5(2)=W(2)*Z9+P(2)
      Z9=Z9+XL3/W(3)
      P6(1)=W(1)*Z9+P(1)
```

```
      P6(2)=W(2)*Z9+P(2)
COM   Z=0 AND Z=XL3 PLANES
      IF(P5(1).GE.XL1.OR.P5(1).LE.0.0) GOTO 16
      IF(P5(2).GE.XL2.OR.P5(2).LE.0.0) GOTO 16
      IHIT=IHIT+1
      DO 15 I=1,3
      IF(IHIT.EQ.2)GOTO 14
      PIN(I)=P5(I) $ NPL(1)=5 $ GOTO 15
   14 POUT(I)=P5(I) $ NPL(2)=5
   15 CONTINUE
      IF(IHIT.EQ.2) GOTO 20
   16 IF(P6(1).GE.XL1.OR.P6(1).LE.0.0) GOTO 203
      IF(P6(2).GE.XL2.OR.P6(2).LE.0.0) GOTO 203
      IHIT=IHIT+1
      DO 18 I=1,3
      POUT(I)=P6(I) $ NPL(2)=6
   18 CONTINUE
  203 IF(IHIT.EQ.2) GO TO 20
      IF(IHIT.EQ.0) GO TO 52
COM   QUESTIONABLE RAY
   19 PRINT 50,W,P
   50 FORMAT(6E14.7)
      GO TO 52
   20 Z8=0.0 $ Z9=0.0
      DO 21 I=1,3
      Z8=Z8+(PIN(I)-P(I))**2
      Z9=Z9+(POUT(I)-P(I))**2
   21 CONTINUE
      IF(Z8.LE.Z9) GOTO 23
      DO 22 I=1,3
      Z7=PIN(I)
      PIN(I)=POUT(I)
      POUT(I)=Z7
   22 CONTINUE
      Z7=NPL(1)     $ Z6=Z8
      NPL(1)=NPL(2)     $ Z8=Z9
      NPL(2)=Z7     $ Z9=Z6
   23 SLR = SQRTF(Z9) - SQRTF(Z8)
   25 DO 51 I=1,3
      P(I) = PIN(I)
   51 CONTINUE
   52 RETURN
      END
C
C
      SUBROUTINE CHECK
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
      DO 1 I = 1,2
```

```
      IF(W(I).NE.0.0)  GO TO 1
      X = P(I)/GRID(I)
      IX = XFIXF(X)
      IF(X.NE.FLOATF(IX))  GO TO 1
      X      = URAN31(ISEED)
      P(I) = P(I) + 0.00001
      IF(X.GT.0.5)  P(I) = P(I) - 0.00002
    1 CONTINUE
      IF(W(3).NE.0.0) GO TO 2
      IF(P(3).GT.BKPT)  GO TO 3
      X = P(3)/GRID(3)
      IX = XFIXF(X)
      IF(X.NE.FLOATF(IX)) GO TO 2
      GO TO 4
    3 X = (P(3) - BKPT)/GRID(4)
      IX = XFIXF(X)
      IF(X.NE.FLOATF(IX))  GO TO 2
    4 X      = URAN31(ISEED)
      P(3) = P(3) + 0.00001
      IF(X.GT.0.5)  P(3) = P(3) - 0.00002
    2 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE CROSS(SLRC)
      COMMON/LATEN/JLAT(2,100),NLAT(20),ILAT,NLATT,ISECT,ILATX,ISECTT,
     * PLAT(4,100),PTAR(6,100),PBDY,PBOX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
      COMMON/POINT/PS(3),PR(3),PE(3),PC(3),DELR,NFLG3
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
      COMMON/LAT/NX,NY,NZ,NSECT,ISL
COM   DETERMINES IF SECTION CROSSING
      ISECTT=ISECT+1
      SLRC = 2000000.0
      IF(W(3).GE.0.0.AND.ISECT.EQ.NSECT)GOTO 3
      IF(W(3).LE.0.0.AND.ISECT.EQ.1)  GO TO 3
      IF(W(3).EQ.0.0)  GO TO 3
      IF(W(3).LT.0.0) GO TO 1
      PC(3) = SPLT(ISECT)
      GO TO 2
    1 PC(3) = SPLT(ISECT - 1)
      ISECTT = ISECT - 1
    2 CONTINUE
      SLRC = (PC(3) - PS(3))/W(3)
      PC(2) = PS(2) + W(2)*SLRC
      PC(1) = PS(1) + W(1)*SLRC
    3 RETURN
      END
```

```
C
C
      SUBROUTINE EDIT
      COMMON/MANN/MAN(110,55,6),NTEST
      COMMON/EVAL/VI(200),NVI(200),VI2(200),FACT(11)
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
  100 FORMAT(1H )
  101 FORMAT(A10,5X,A10,A1,2X,A10,A1,5X,A7)
  102 FORMAT(I10,A5,E11.4,A2,E11.4,A5,I7)
  103 FORMAT(5A10)
  110 FORMAT(1H1)
      CAP1 = 10H INCREMENTS CAP2 = 5H* * *S CAP3 = 2H+-
      CAP4 = 7HNO RAYS     $ CAP5 = 10H STAND DEVS CAP6 = 1H
      CAP7 = 10H  VUL INDES CAP8 = 1HX$CAP9=10H- - - - -
      CALL VAR
      IZ=0
   10 WRITE(6,110)
      WRITE(6,101)CAP1,CAP7,CAP8,CAP5,CAP6,CAP4
      WRITE(6,103) CAP9,CAP9,CAP9,CAP9,CAP9
   11 IZ = IZ + 1
  112 WRITE(6,102) IZ,CAP2,VI(IZ),CAP3,VI2(IZ),CAP2,NVI(IZ)
      IF(NVI(IZ+1).EQ.0) GO TO 20
      IF(MOD(IZ,50).EQ.0) GO TO 10
      GO TO 11
   20 RETURN
      END
C
C
      SUBROUTINE EVEN(JEXIT)
COM   BRINGS PBDY TO EVEN NUMBER OF DELR OR EXITS BOX OR CROSSES SECTION
      COMMON/MANN/MAN(110,55,6),NTEST
      COMMON/LATEN/JLAT(2,100),NLAT(20),ILAT,NLATT,ISECT,ILATX,ISECTT,
     * PLAT(4,100),PTAR(6,100),PBDY,PBOX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
      COMMON/EVAL/VI(200),NVI(200),VI2(200),FACT(11)
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      COMMON/POINT/PS(3),PR(3),PE(3),PC(3),DELR,NFLG3
      JEXIT = 0
    7 CALL CROSS(SLRC)
      PDEL = PBDY - DELR*FLOATF(NDEL)
      Z9 = DELR - PDEL
      IF(SLRC.LE.Z9) GO TO 20
      IF(SLR - PBOX.LT.Z9 + 1.0E-10) GO TO 28
      CALL LATIS(PS,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).EQ.0) GO TO 31
      RN1    = URAN31(ISEED)
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```
      DO 2 IZ = 1,3
      PE(IZ) = PS(IZ) + Z9*W(IZ)
      PR(IZ) = PS(IZ) + Z9*W(IZ)*RN1
    2 CONTINUE
      CALL LATIS(PE,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).EQ.0) GO TO 3
      CALL LATIS(PR,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).EQ.0) GO TO 3
      CALL SCORE(SC,ISC,I,J,K)
      SCPT = SCPT + Z9*SC*FACT(ISC)/DELR
      INX = 11
      WRITE(6,1000) PS,PE,W,INX
 1000 FORMAT(9(E12.4,1X),/,I5)
      DO 130 IZ = 1,3
      PS(IZ) = PE(IZ)
  130 CONTINUE
      PBDY = DELR*FLOATF(NDEL+1)  $ PBOX = PBOX + Z9
      GOTO 51
    3 CALL TRACE(Z9)
      IZ = 0
    5 IZ = IZ + 1
      IF(DIST(2,IZ).EQ.0.0) GO TO 14
      PDEL = PDEL + DIST(1,IZ)
      ISC = IDIST(IZ)
      IF(PDEL.LT.DELR) GO TO 17
      DIST(1,IZ) = DIST(1,IZ) - PDEL + DELR
      NCELL = IZ
   17 SCPT = SCPT + DIST(1,IZ)*DIST(2,IZ)*FACT(ISC)/DELR
      PBDY = PBDY + DIST(1,IZ)
   14 PBOX = PBOX + DIST(1,IZ)
      DO 6 IX = 1,3
      PS(IX) = PS(IX) + DIST(1,IZ)*W(IX)
    6 CONTINUE
      IF(IZ.LT.NCELL) GO TO 5
      INX = 12
      WRITE(6,1000) PS,PE,W,INX
      IF(PDEL.LT.DELR) GO TO 7
      GOTO 51
    8 CALL CROSS(SLRC)
   31 IF(SLRC.LE.Z9) GO TO 20
      IF(SLR - PBOX.LT.Z9 + 1.0E-10) GO TO 28
      DO 9 IZ = 1,3
      PE(IZ) = PS(IZ) + Z9*W(IZ)
    9 CONTINUE
      CALL LATIS(PE,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).GT.0) GO TO 3
      DO 62 IZ = 1,3
```

```
      PS(IZ) = PE(IZ)
   62 CONTINUE
      PBOX = PBOX + Z9
      Z9 = DELR
      INX = 13
      WRITE(6,1000) PS,PE,W,INX
      GOTO 8
   20 IF(SLR - PBOX.LT.SLRC + 1.0E-10) GO TO 28
      IFLAG = 1 $ Z9 = SLRC
      GO TO 29
   28 IFLAG = 0 $ Z9 = SLR - PBOX
   29 CALL TRACE(Z9)
      INX = 14
      WRITE(6,1000) PS,PE,W,INX
      IZ = 0 $ IFLAG2 = 0
   21 IZ = IZ +1
      IF(DIST(2,IZ).EQ.0.0) GO TO 24
      ISC = IDIST(IZ)
      PDEL = PDEL + DIST(1,IZ)
      IF(PDEL.LT.DELR) GO TO 27
      DIST(1,IZ) = DIST(1,IZ) - PDEL + DELR
      NCELL = IZ      $ IFLAG2 = 1
   27 SCPT = SCPT + DIST(1,IZ)*DIST(2,IZ)*FACT(ISC)/DELR
      PBDY = PBDY + DIST(1,IZ)
   24 PBOX = PBOX + DIST(1,IZ)
      DO 25 IX = 1,3
      PS(IX) = PS(IX) + DIST(1,IZ)*W(IX)
   25 CONTINUE
      IF(IZ.LT.NCELL) GO TO 21
      IF(IFLAG2.EQ.1) GO TO 51
      JEXIT = 1
      IF(IFLAG.EQ.0) GO TO 52
      IF(NFL33.EQ.3) NLATT = 0
      IF(ILATX.GT.1) GO TO 40
      NLATT = NLATT + 1    $ IZ = NLATT
      GO TO 41
   40 IZ = ILAT
   41 CONTINUE
      NLAT(ISECTT) = NLAT(ISECTT) + 1
      CALL LATENT(1,IZ,PC)
      IF(NFL33.LT.3) GO TO 100
      CALL LOAD(ISECTT)
      ISECT = ISECTT     $ ILAT = 1
      GO TO 100
   52 Z9 = DELR*FLOATF(NDEL)
      IF(PBDY.EQ.Z9) GO TO 50
      RN1=URAN31(ISEED)
      IF(RN1.GT.PBDY-Z9)GO TO 50
      SC = SCPT*DELR/(PBDY - Z9)
      GO TO 51
```

```
   50 SC = 0.0    $  GO TO 100
   51 NDEL = NDEL + 1
      CALL TALLY(NDEL,SC,11)
  100 SCPT = 0.0
      RETURN
      END
C
C
      SUBROUTINE HEMI
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
      IF(NFLG1.EQ.8)GOTO 6
      CSTHT = URAN31(ISEED)
      R=R2
      GOTO 1
    6 R=SQRTF(GCR**2+GCH**2)
      CSTHT=GCR/R
    1 X1     = URAN31(ISEED)
      X2     = URAN31(ISEED)
      X1S=X1**2
      X2S=X2**2
      T=X1S+X2S
      IF(T.GE.1.0)GOTO 1
      CSPHI=(X1S-X2S)/T
      SNPHI=2.0*X1*X2/T
      X1     = URAN31(ISEED)
      IF(X1.GT.0.5) GOTO 2
      SNPHI=-SNPHI
    2 SNTHT=SQRTF(1.0-CSTHT**2)
      WP(1)=SNTHT*SNPHI
      WP(2)=SNTHT*CSPHI
      WP(3)=CSTHT
      IF(NFLG1.EQ.2) GOTO 8
      IF(NFLG1.GT.3) GOTO 3
      WP(3)=-WP(3) $ GOTO 8
    3 IF(NFLG1.GT.5) GOTO 5
      X1=ABSF(WP(2))
      WP(3)=X1*WP(3)/WP(2)
      IF(NFLG1.GT.4) GOTO 4
      WP(2)=X1 $ GOTO 8
    4 WP(2)=-X1 $ GOTO 8
    5 IF(NFLG1.GT.7) GOTO 8
      X1=ABSF(WP(1))
      WP(3)=X1*WP(3)/WP(1)
      IF(NFLG1.GT.6) GOTO 7
      WP(1)=X1 $ GOTO 8
    7 WP(1)=-X1
    8 DO 10 I=1,3
      PO(I)=R*WP(I) $ WP(I)=-WP(I)
```

```
      P(I) = PO(I)
   10 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE INX3
COM   CALCULATES EXIT POINT FROM CELL
      COMMON/TRAX/P1(3),P2(3),BOUND(6),PL1,PL2,PL3,Z9
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      IF(W(1).EQ.0.0)  GO TO 2
      P2(1) = PL1
      Z9 = (PL1 - P1(1))/W(1)
      P2(2) = P1(2) + Z9*W(2)
      P2(3) = P1(3) + Z9*W(3)
      IF(P2(2).GT.BOUND(4).OR.P2(2).LT.BOUND(3))  GO TO 2
      IF(P2(3).GT.BOUND(6).OR.P2(3).LT.BOUND(5))  GO TO 2
      GO TO 5
    2 IF(W(2).EQ.0.0)  GO TO 3
      P2(2) = PL2
      Z9 = (PL2 - P1(2))/W(2)
      P2(1) = P1(1) + Z9*W(1)
      P2(3) = P1(3) + Z9*W(3)
      IF(P2(1).GT.BOUND(2).OR.P2(1).LT.BOUND(1))  GO TO 3
      IF(P2(3).GT.BOUND(6).OR.P2(3).LT.BOUND(5))  GO TO 3
      GO TO 5
    3 IF(W(3).EQ.0.0)  GO TO 4
      P2(3) = PL3
      Z9 = (PL3 - P1(3))/W(3)
      P2(1) = P1(1) + Z9*W(1)
      P2(2) = P1(2) + Z9*W(2)
      IF(P2(1).GT.BOUND(2).OR.P2(1).LT.BOUND(1))  GO TO 4
      IF(P2(2).GT.BOUND(4).OR.P2(2).LT.BOUND(3))  GO TO 4
      GO TO 5
    4 CONTINUE
COM   TRACE ERROR
    5 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE ISOT
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
      X1     = URAN31(ISEED)
      IF(R2.GE.R1) GOTO 1
      CSTHT=2.0*X1-1.0 $ SPCT=1.0
      GOTO 2
```

```
    1 X2 = SQRTF(R2**2 - R1**2)/R2
      SPCT = 1.0 - X2
      CSTHT = 1.0 - X1*(1.0 - X2)
    2 X1     = URAN31(ISEED)
      X2     = URAN31(ISEED)
      X1S=X1**2
      X2S=X2**2
      T=X1S+X2S
      IF(T.GE.1.0) GO TO 2
      CSPHI=(X1S-X2S)/T
      SNPHI=2.0*X1*X2/T
      X1     = URAN31(ISEED)
      IF(X1.GT.0.5) GOTO 3
      SNPHI=-SNPHI
    3 T1=WP(1)**2+WP(2)**2
      T3=1.0-CSTHT**2
      T4=T3/T1
      IF(T1.GT.1.0E-10)GOTO 4
      SNTHT=SQRTF(T3)
      W(1)=SNTHT*CSPHI
      W(2)=SNTHT*SNPHI
      W(3)=CSTHT*WP(3)
      GOTO 5
    4 T2=SQRTF(T4)
      W(1)=T2*(WP(1)*WP(3)*SNPHI+WP(2)*CSPHI)+WP(1)*CSTHT
      W(2)=T2*(WP(2)*WP(3)*SNPHI-WP(1)*CSPHI)+WP(2)*CSTHT
      W(3)=WP(3)*CSTHT-T1*T2*SNPHI
    5 RETURN
      END
C
C
      SUBROUTINE LATENT(IL,IP,PI)
COM   STORES AND RETRIEVES LATENT RAYS
      DIMENSION PI(3)
      COMMON/MANV/MAN(110,55,6),NTEST
      COMMON/LATEN/JLAT(2,100),NLAT(20),ILAT,NLATT,ISECT,ILATX,ISECTT,
     * PLAT(4,100),PTAR(6,100),PBDY,PBOX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      IF(IL.GT.0) GO TO 2
      PBDY = PLAT(1,IP)
      PBOX = PLAT(2,IP)
      SLR  = PLAT(3,IP)
      SCPT = PLAT(4,IP)
      DO 1 IZ = 1,3
      PI(IZ) = PTAR(IZ,IP)
      W(IZ) = PTAR(IZ+3,IP)
    1 CONTINUE
      ISECT = JLAT(1,IP)
```

```
      NDEL = JLAT(2,IP)
      GO TO 10
    2 PLAT(1,IP) = PBDY
      PLAT(2,IP) = PROX
      PLAT(3,IP) = SLR
      PLAT(4,IP) = SCPT
      DO 3 IZ = 1,3
      PTAR(IZ,IP) = PI(IZ)
      PTAR(IZ+3,IP) = W(IZ)
    3 CONTINUE
      JLAT(1,IP) = ISECTT
      JLAT(2,IP) = NDEL
   10 RETURN
      END
C
C
      SUBROUTINE LATIS(PI,I,J,K)
      DIMENSION PI(3),PH(3)
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
      COMMON/LAT/NX,NY,NZ,NSECT,ISL
      COMMON/INDEX/I1,J1,K1
COM   LOCATES CELL I,J,K FOR POINT P
      DO 13 IZ=1,3
      PH(IZ)=PI(IZ)
   13 CONTINUE
19    IZ=0
12    IZ=IZ+1
      IF(IZ.LT.3) GO TO 102
      IF(PI(3).GT.BKPT) GO TO 103
102   X=PI(IZ)/GRID(IZ)
      GO TO 104
103   XBKPT=FLOATF(IBKPT)
      X=XBKPT+(PI(3)-BKPT)/GRID(4)
104   K=XFIXF(X)
      IF(X.LT.0.0) K=K-1
      KK=K
      IF(W(IZ).GT.0.0) KK=K+1
      XK=FLOATF(KK)
      XXK=X-XK
      IF(W(IZ).GT.0.0)  XXK=-XXK
      IF(XXK.GT.1.0E-12) GO TO 107
      IF(IZ.LT.3) GO TO 105
      IF(KK.LT.IBKPT) GO TO 105
      PI(3)=BKPT+(XK-XBKPT)*GRID(4)
      PH(3)=PI(3) $GO TO 3
105   PI(IZ)=XK*GRID(IZ)
      PH(IZ)=PI(IZ) $ GO TO 3
107   GOTO (1,2,10),IZ
```

```
1       I=K $GO TO 12
2       J=K $GO TO 12
      3 CONTINUE
        DO 4 IZ = 1,3
        PI(IZ) = PI(IZ) + 0.000001*W(IZ)
      4 CONTINUE
        GO TO 19
     10 DO 11 IZ = 1,3
        PI(IZ)=PH(IZ)
     11 CONTINUE
        I = I + 1 $ J = J + 1 $ K = K + 1
        I1 = I $ J1 = J $ K1 = K
        IF(I.GT.NX) I = I - 1
        IF(I.LT.1) I = I + 1
        IF(J.GT.NY) J = J - 1
        IF(J.LT.1) J = J + 1
        IF(K.GT.NZ) K = K - 1
        IF(K.LT.1) K = K + 1
        RETURN
        END
C
C
        SUBROUTINE LOAD(ISECT)
C       LOADS LETHALITY DESCRIPTION INTO CORE
C       ISECT EQUALS SECTION  NUMBER TO BE LOADED(RECORD) 1-3
C       NSECT EQUALS NUMBER OF SECTIONS (3)
C       NREM EQUALS  NUMBER OF VOID SLICES IN LAST SECTION  (?)
        COMMON/MANN/MAN(110,55,6),NTEST
        COMMON/LAT/NX,NY,NZ,NSECT,ISL
        DIMENSION NAME(4)
C       DEFINE DISC FILES TO BE UTILIZED
        DATA DISC2/10H55D24 KMAN/
        DATA FILE2/10HBODY PARTS/
C       OPEN THE DISC
        CALL DISCOL(3,NAME,DISC2)
        IF(NTEST.EQ.1) GO TO 999
        CALL DISCRD(FILE2,ISECT,1,MAN)
        GO TO 1000
999     CALL TEST(ISECT)
1000    RETURN
        END
C
C
        SUBROUTINE LOCATE(KP,IS)
        COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
        COMMON/LAT/NX,NY,NZ,NSECT,ISL
COM     CALCULATES MAN K FROM POINT K
        IS=0
     21 IS=IS+1
        IF(KP.GT.IS*ISL)GOTO 21
```

```
      KP = KP - ISL*(IS - 1)
      RETURN
      END
C
C
      SUBROUTINE SCORE(SC,ISC,I,J,K)
      COMMON/MANN/MAN(110,55,6),NTEST
      ISC = MAN(I,J,K)
      SC = FLOATF(ISC)
      RETURN
      END
      SUBROUTINE SORC
      COMMON/LATEN/JLAT(2,100),NLAT(20),ILAT,NLATT,ISECT,ILATX,ISECTT,
     * PLAT(4,100),PTAR(6,100),PHDY,PBOX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
      IF(IHIST.GT.1) GO TO 12
      IF(NFLG1.GT.1) GO TO 8
      IF(NPTS.GT.1)  GO TO 2
      DO 1 I = 1,3
      P(I) = PO(I)
    1 CONTINUE
      GO TO 4
    2 DO 3 I = 1,3
      P(I) = PTAR(I,IPT)
      W(I) = PTAR(I+3,IPT)
    3 CONTINUE
    4 CONTINUE
      IF(NFLG2.GT.2) GO TO 13
      IF(NFLG2.GT.1) GO TO 5
      R2 = (P(1) - 0.5*XL1)**2
      R2 = R2 + (P(2) - 0.5*XL2)**2
      R2 = R2 + (P(3) - 0.5*XL3)**2
      R2 = SQRTF(R2)
      GO TO 11
    5 CONTINUE
      R2 = 0.0
      DO 6 I = 1,3
      R2 = R2 + (P(I) - BULSI(I))**2
    6 CONTINUE
      R2=SQRTF(R2)
      DO 7 I = 1,3
      WP(I) = (BULSI(I) - P(I))/R2
    7 CONTINUE
      GO TO 12
    8 IF(NFLG1.GT.8) GO TO 9
      CALL HEMI
      GO TO 10
```

```
    9 CALL ARC(NARC)
   10 CALL TRANS
   11 WP(1) = (0.5*XL1 - P(1))/R2
      WP(2) = (0.5*XL2 - P(2))/R2
      WP(3) = (0.5*XL3 - P(3))/R2
   12 CONTINUE
      CALL AD
   13 RETURN
      END
C
C
      SUBROUTINE TALLY(IP,SC,ISC)
      COMMON/MANN/MAN(110,55,6),NTEST
      COMMON/EVAL/VI(200),NVI(200),VI2(200),FACT(11)
      SC = SC*FACT(ISC)
      VI(IP) = VI(IP) + SC
      VI2(IP) = VI2(IP) + SC*SC
    3 NVI(IP) = NVI(IP) + 1
      RETURN
      END
C
C
      SUBROUTINE TEST(ISECT)
      COMMON/MANN/MAN(110,55,6),NTEST
      DO 12 I = 1,110
      DO 12 J = 1,55
      DO 12 K = 1,6
      MAN(I,J,K) = 0
   12 CONTINUE
      DO 1 I =50,60
      DO 1 J =1,55
      DO 1 K =1,6
      MAN(I,J,K) = I - 50
    1 CONTINUE
      DO 2 J =24,32
      DO 2 I =1,110
      DO 2 K =1,6
      MAN(I,J,K) = J - 23
    2 CONTINUE
      IF(ISECT.GT.8) GO TO 5
      IF(ISECT.LT.7) GO TO 5
      DO 3 I = 1,110
      DO 3 J = 1,55
      DO 3 K = 1,6
      MAN(I,J,K) = 10
    3 CONTINUE
    5 RETURN
      END
C
C
```

```
      SUBROUTINE TRACE(R)
COM   TRACKS THROUGH CELLS AND STORES SCORES AND DISTANCES
      COMMON/SORS/*P(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/TRAX/P1(3),P2(3),BOUND(6),PL1,PL2,PL3,Z9
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
      COMMON/POINT/PS(3),PR(3),PE(3),PC(3),DELR,NFLG3
      COMMON/INDEX/I1,J1,K1
COM   INITIALIZE ARRAYS
      DO 11 J = 1,5
      IDIST(J) = 0
      DO 11 I = 1,2
      DIST(I,J) = 0.0
   11 CONTINUE
      DO 12 J = 1,3
      P1(J) = PS(J)
   12 CONTINUE
      NCELL = 0  $ PCELL = 0.0
   10 NCELL = NCELL + 1
      CALL LATIS(P1,I,J,K)
      PL1 = GRID(1)*FLOATF(I1)
      PL2 = GRID(2)*FLOATF(J1)
      IF(K.GT.IBKPT) GO TO 1
      PL3 = GRID(3)*FLOATF(K1)
      ZNZ = GRID(3)    $  GO TO 2
    1 PL3 = BKPT + GRID(4)*FLOATF(K1 - IBKPT)
      ZNZ = GRID(4)
    2 CONTINUE
      BOUND(2) = PL1
      BOUND(4) = PL2
      BOUND(6) = PL3
      BOUND(1) = PL1 - GRID(1)
      BOUND(3) = PL2 - GRID(2)
      BOUND(5) = PL3 - ZNZ
      IF(W(1).LT.0.0)  PL1 = PL1 - GRID(1)
      IF(W(2).LT.0.0)  PL2 = PL2 - GRID(2)
      IF(W(3).LT.0.0)  PL3 = PL3 - ZNZ
      CALL INX3
      CALL LOCATE(K,ISECTT)
      CALL SCORE(SC,ISC,I,J,K)
      DIST(2,NCELL) = SC
      IDIST(NCELL) = ISC
      IF(PCELL + Z9.GE.R)  GO TO 14
      DIST(1,NCELL) = Z9
      PCELL = PCELL + Z9
      DO 13 IZ = 1,3
      P1(IZ) = P2(IZ)
   13 CONTINUE
      IF(R - PCELL.LT.10E-12) GO TO 7
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```
      GO TO 10
   14 DIST(1,NCELL) = R - PCELL
    7 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE TRACK(IL)
      COMMON/MANN/MAN(110,55,6),NTEST
      COMMON/LATEN/JLAT(2,100),NLAT(20),ILAT,NLATT,ISECT,ILATX,ISECTT,
     * PLAT(4,100),PTAR(6,100),PBDY,PBOX,SCPT,NDEL,IHIST,IPT,NARC,NPTS
      COMMON/EVAL/VI(200),NVI(200),VI2(200),FACT(11)
      COMMON/SORS/WP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
      COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
      COMMON/POINT/PS(3),PR(3),PE(3),PC(3),DELR,NFLG3
      COMMON/LATIX/GRID(4),BKPT,IBKPT,SPLT(19)
      COMMON/INDEX/I1,J1,K1
      COMMON/LODE/NLOAD
COM   TRACKS INITIAL RAYS,LATENTS,OR RAYS RETURNED FROM EVEN
   80 JEXIT = 0
      IF(IL.EQ.1)  GO TO 120
      CALL LATENT(0,ILAT,PS)
      WRITE(6,525) ILAT,NLATT,ISECT,ISECTT,JEXIT,NDEL
  525 FORMAT(10(2X,I5))
      JLAT(1,ILAT) = 0
      NLAT(ISECT) = NLAT(ISECT) - 1
      IF(PBDY.EQ.0.0) GO TO 2
      CALL EVEN(JEXIT)          $  GO TO 4
  120 DO 1 IZ = 1,3
      PS(IZ) = P(IZ)
    1 CONTINUE
      INX = 5
      WRITE(6,1000) PS,PE,W,INX
 1000 FORMAT(9(E12.4,1X),/,I5)
      PBDY = 0.0  $ PBOX = 0.0  $ NDEL = 0
    2 CONTINUE
    4 IF(JEXIT.EQ.1) GO TO 70
  132 CALL LATIS(PS,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(ISECT.EQ.ISECTT) GO TO 43
COM   STORE LATENT
      DO 25 IZ = 1,3
      PC(IZ) = PS(IZ)
   25 CONTINUE
  133 IF(NFLG3.EQ.3) NLATT = 0
      IF(ILATX.GT.1) GO TO 40
      NLATT = NLATT + 1   $ IZ = NLATT
      GO TO 41
   40 IZ = ILAT
```

```
   41 CONTINUE
      NLAT(ISECTT) = NLAT(ISECTT) + 1
      CALL LATENT(1,IZ,PC)
      IF(NFL33.LT.3) GO TO 70
      CALL LOAD(ISECTT)
      ISECT = ISECTT  $  ILAT = 1
      GO TO 80
COM   END OF LATENT STORAGE
   43 CONTINUE
      CALL CROSS(SLRC)
      IF(SLRC.LE.DELR) GO TO 20
      IF(SLR - PBOX.LT.DELR + 1.0E-10) GO TO 30
      IF(MAN(I,J,K).EQ.0)  GO TO 7
      RN1    = URAN31(ISEED)
      DO 82 IZ = 1,3
      PE(IZ) = PS(IZ) + DELR*W(IZ)
      PR(IZ) = PS(IZ) + DELR*W(IZ)*RN1
   82 CONTINUE
      CALL LATIS(PE,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).EQ.0) GO TO 3
      CALL LATIS(PR,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).EQ.0)  GO TO 3
      CALL SCORE(SC,ISC,I,J,K)
      NDEL = NDEL + 1
      PBDY = DELR*FLOATF(NDEL)
      PBOX = PBOX + DELR
      CALL TALLY(NDEL,SC,ISC)
      INX = 1
      WRITE(6,1000) PS,PE,W,INX
      DO 130 IZ = 1,3
      PS(IZ) = PE(IZ)
  130 CONTINUE
      GO TO  43
    3 CALL TRACE(DELR)
      DO 5 IZ = 1,NCELL
      IF(DIST(2,IZ).EQ.0.0)  GO TO 14
      ISC = IDIST(IZ)
      SCPT = SCPT + DIST(1,IZ)*DIST(2,IZ)*FACT(ISC)/DELR
      PBDY = PBDY + DIST(1,IZ)
   14 PBOX = PBOX + DIST(1,IZ)
    5 CONTINUE
      INX = 2
      WRITE(6,1000) PS,PE,W,INX
      DO 6 IZ = 1,3
      PS(IZ) = PE(IZ)
    6 CONTINUE
      CALL EVEN(JEXIT)
      GO TO 4
```

```
    8 CALL CROSS(SLRC)
    7 IF(SLRC.LE.DELR) GO TO 20
      IF(SLR - PBOX.LT.DELR + 1.0E-10) GO TO 30
      DO 9 IZ = 1,3
      PE(IZ) = PS(IZ) + DELR*W(IZ)
    9 CONTINUE
      CALL LATIS(PE,I,J,K)
      CALL LOCATE(K,ISECTT)
      IF(MAN(I,J,K).GT.0) GO TO 3
   61 DO 62 IZ = 1,3
      PS(IZ) = PE(IZ)
   62 CONTINUE
      PBOX = PBOX + DELR
      GO TO 8
   20 IF(SLR - PBOX.LT.SLRC + 1.0E-10) GO TO 30
      CALL TRACE(SLRC)
      DO 21 IZ = 1,NCELL
      IF(DIST(2,IZ).EQ.0.0) GO TO 24
      ISC = IDIST(IZ)
      SCPT = SCPT + DIST(1,IZ)*DIST(2,IZ)*FACT(ISC)/DELR
      PBDY = PBDY + DIST(1,IZ)
   24 PBOX = PBOX + DIST(1,IZ)
      INX = 3
      WRITE(6,1000) PS,PE,W,INX
   21 CONTINUE
      GO TO 133
   30 CALL TRACE(SLR - PBOX)
      DO 31 IZ = 1,NCELL
      IF(DIST(2,IZ).EQ.0.0) GO TO 34
      ISC = IDIST(IZ)
      SCPT = SCPT + DIST(1,IZ)*DIST(2,IZ)*FACT(ISC)/DELR
      PBDY = PBDY + DIST(1,IZ)
   34 PBOX = PBOX + DIST(1,IZ)
   31 CONTINUE
      INX = 4
      WRITE(6,1000) PS,PE,W,INX
      Z8 = DELR*FLOATF(NDEL)
      IF(PBDY.EQ.Z8) GO TO 70
      RN1=URAN31(ISEED)
      IF(RN1.GT.PBDY-Z8)GO TO 70
      SC = SCPT*DELR/(PBDY - Z8)
   51 NDEL = NDEL + 1
      CALL TALLY(NDEL,SC,11)
   70 SCPT = 0.0
  100 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE TRANS
```

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```
COM    TRANSLATES POINT
       COMMON/TRAC/SLR,XL1,XL2,XL3,NHITS,DIST(2,10),IDIST(10),NCELL
       COMMON/SORS/KP(3),W(3),P(3),PO(3),BULSI(3),SPCT,ISEED,JSEED,
     * SNT,CST
       COMMON/MISC/R1,R2,GCR,GCH,NFLG1,NFLG2,SD1,SD2,GW1,GW2
       P(1)=P(1)+0.5*XL1
       P(2)=P(2)+0.5*XL2
       IF(NFLG1.EQ.8) GO TO 100
       P(3)=P(3)+0.5*XL3
  100  RETURN
       END
C
C
       SUBROUTINE VAR
       COMMON/MANN/MAN(110,55,6),NTEST
       COMMON/EVAL/VI(200),NVI(200),VI2(200),FACT(11)
       IZ=0
   11  IZ=IZ+1
       IF(NVI(IZ).EQ.0) GOTO 20
       IF(NVI(IZ).GT.1) GOTO 12
       VI2(IZ)=9.99 $ GOTO 11
   12  I=NVI(IZ)
       Z8=FLOATF(I)
       Z9=VI(IZ)/Z8
       VI(IZ)=Z9
       Z9=Z9*Z9*Z8
       Z9=VI2(IZ)-Z9
       IF(Z9.LT.0.0.AND.Z9.GT.-1.0E-06)Z9=0.0
       IF(Z9)21,16,16
21     WRITE(6,100)Z9
100    FORMAT(30X,'THE VALUE OF Z9 IS',2X,E12.5)
       GO TO 11
   16  Z9=Z9/(Z8-1.0)
       Z9=SQRTF(Z9)
       VI2(IZ)=Z9
       GO TO 11
   20  RETURN
       END
C
C
*      COMPILE DISC,NRAN31,ALL
*      COMPILE DISC,URAN31,ALL
*      LIST
*      DATA
       BULSI CHECK BIVAR DISTRIB
  11111111  11113111
     1     1     1
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